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ELECTROLYTIC COPPER REFINING.

BY

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INTRODUCTION AND ACKNOWLEDGMENT.

THE great difficulties encountered in preparing the following monograph can be fully appreciated only by those who have undertaken a similar publication, and might have prevented the consummation of this work, undertaken at the request of several distinguished foreign engineers, had I not been assured of the cooperation of these gentlemen and of some of the leading electrochemists and refiners in the United States.

It is a well-known fact that the managers of but few electrolytic plants grant technical visitors, and especially writers, access to their works, and that it has hitherto been extremely difficult or impossible, therefore, to secure accurate descriptions of certain American and European refining appliances, methods, and works. Fortunately, I have had the opportunity of personally inspecting many of the most important electrolytic refineries in the world, in several of which I have worked, and am therefore enabled to present certain desirable information accurately for the first time in print, and to supply close estimates of other much-sought-for data.

Requests for information were addressed directly or indirectly to practically every electrorefiner here and abroad, with the object of making the following monograph as far as possible an authoritative accurate, comprehensive and

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thoroughly up-to-date handbook. Its scope is indicated by the numerous items of the table of contents.

Every electrolytic copper-refining plant in the world that is now in commercial operation, I believe, is herein tabulated with its actual or estimated output, arrangement of electrodes, location, etc., and is described as fully as a personal inspection and inquiry, examinations of American, British, German and French patents and literature, or special means of securing information at my command, permitted. The data thus gathered at the expense of considerable work will, I trust, be appreciated by copper refiners especially, and aid in stimulating progress not only in their rapidly extending art, but in electrometallurgy generally.

I take pleasure in acknowledging my indebtedness to Mr. Lawrence Addicks, Raritan Copper Works, Perth Amboy, N. J.; Mr. Ottokar Hofmann, Director of the Southwest Chemical Co., Argentine, Kan.; and Mr. R. L. Whitehead, Manager of the Seattle Smelting and Refining Co., Seattle, Washington, for permitting my use of their excellent articles in *The Mineral Industry*, vols. ix and x; and to Dr. Jos. Struthers and the other editors and publishers of the *Engineering and Mining Journal* and *Mineral Industry* for a similar kindness extended by them; Mr. Wm. Thum, Ass't Sup't of the Balbach Electrolytic Copper Works, Newark, N. J.; and Mr. J. B. C. Kershaw, Electrochemist, London, for their valued cooperation; Prof. W. Borchers, Aachen, Germany, for placing technical data in his "Elektro-Metallurgie" at my disposal; Mr. Victor Engelhardt, Chief Engineer, Siemens and Halske Co., Vienna, who assisted in obtaining information regarding European plants and furnished descriptions of the Austro-Hungarian refineries; Dr. Gustav Koelle, Director of the Von Siemens Copper Works, Kedabeg, Russia, whose interesting description of the Kalakent Works is given in

Chapter II, and to the following electrochemists, metallurgists or engineers for rendering valuable assistance, or managers of refineries for allowing me access to their plants:

Mr. A. L. Walker, Manager, Perth Amboy plant of the American Smelting and Refining Co.; Mr. Ed. Balbach, Jr., President, Balbach Smelting and Refining Co.; Mr. M. B. Patch, Superintendent, Buffalo Copper Works; Mr. J. C. McCoy, Manager, Raritan Copper Works; Mr. W. A. McCoy, Superintendent, Raritan Electrolytic Works; Dr. James Douglas, President, Copper Queen Cons. Mining Co.; Dr. Edward Keller, Anaconda Mining Co.; Mr. J. T. Morrow, Superintendent, Boston and Montana Cons. Copper and Silver Mining Co.; and the superintendents of the Anaconda, Baltimore, Blue Island, and Nichols refineries in this country, and of the Mansfeld, Oker, and Altenau refineries abroad, as well as the following engineers: Mr. J. R. Watson, Lake Superior Power Co.; Mr. J. H. Hoff, American Bridge Co.; Mr. Willard Pope, Canadian Bridge Co.; Mr. A. L. Roby, Wellman-Seaver Engineering Co., and Mr. G. J. Rockwell, of the Allis-Chalmers Co.

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MODERN ELECTROLYTIC COPPER REFINING.

CHAPTER I.

DEVELOPMENT, METHODS, AND APPARATUS OF ELECTROLYTIC COPPER REFINING.

Historical Data. — The art of electrolytically refining crude copper is based, like the allied art of copper plating, upon various discoveries chiefly made between the years 1800 and 1867, the date of the introduction of the dynamo.

Although more than thirteen hundred years ago Zosimus mentioned the earliest known fact respecting the electro lytic separation of metals, viz., that by immersing a piece of iron in a cuprous solution it acquired a coating of copper, it was first definitely shown in 1800 that copper could be deposited from solution by electric currents, which fact was demonstrated by Cruikshank.

After the discoveries of magneto-electricity by Faraday in 1831 and of electrotyping in 1838 by Jacobi, the greater possibilities of the application of electricity to metal deposition began to be recognized, but not until Elkington's discovery of the art of refining copper in 1865 and the introduction of the dynamo in 1867 was its commercial future assured. Since that time the remarkable growth of electric copper refining is scarcely paralleled in the history of any other industry.

It was nearly thirty-eight years ago that James Elkington, the English silver-plater, invented the commercial electrolytic method of refining crude copper, and in 1869 that he founded the first custom plant using this process, at Pembrey, Wales. The works established by the father of modern copper refining are to-day in successful operation, due chiefly to the remarkable fact that both Elkington's process and apparatus were well conceived and needed but little improvement to bring them up to present standards. However, it was not until the last two decades, when the spread of electric lighting led to an enormous demand for pure copper, and the perfection of the dynamo made possible the cheap generation of current, that the great importance of Elkington's invention was fully realized.

In Germany, according to Schnabel, the first electrolytic refining plant erected was the Hamburg refinery (Norddeutsche Affinerie), built in the late seventies under Wohlwill's management and operated with Gramme machines. Subsequently the Oker refinery (Communion Huettenwerk), in which Siemens machines were used to generate current, was erected under Braeuning's management, and in still more recent years, according to Schnabel, the Mansfeld Copper Co.'s electrolytic plant was started.

In 1879 an experimental plant for refining copper by electrolysis was operated at Phœnixville, Pa., but the first commercial refinery in the United States was built by Edward Balbach, assisted by F. A. Thum, at Newark, N. J., in 1882–83. The refineries at Baltimore, Md., and at Anaconda and Great Falls, Mont., were not started until 1887, 1891, and 1892, respectively, the Raritan Copper Works in 1899, and the De Lamar Works and the new Perth Amboy electrolytic plant in 1902. Sixteen years ago the Balbach and the Bridgeport (Conn.) works were the only large electrolytic plants in America, and their total output was less than 24 tons per diem. Yet to-day there are in

operation ten electrolytic refineries, producing the enormous quantity of 764 tons daily, or nearly two hundred and seventy-nine thousand short tons of copper annually, besides over twenty-seven million ounces of silver and three hundred and forty-six thousand ounces of gold. Thus over 80% of all the copper produced in the United States is now refined in the electrolytic bath, and probably nearly 70% of the entire production of the world is now turned out as electrolytic metal.

Cost of Producing Electrolytic Copper.—Still more astonishing than the above figures of output is a comparison of the cost of producing electrolytic from crude copper ten years ago with the cost to-day. Then it was about $20 per ton, although refiners charged $40 and allowed only 92½% on the commercial value of the silver in the Bessemer or blister copper. Now the cost of refining 98% copper anodes at several of the large works in the United States has actually been lowered to $4 or $5 per ton, it appears, and occasionally contracts for refining from anode to cathode have been closed, I believe, for as low as $7.50. The chief cause of the great reduction in the cost of refining is economy in utilizing power and in handling material.

Definitions and General Principles.—The following definitions from Edward Keller's excellent article in *Mineral Industry*, vol. vii, are reproduced chiefly in order to give students a clear conception of the elementary principles that underlie the practical working of the electrolytic refining process, and thus make the subsequent treatment of the subject more comprehensive:

"Wherever there is any work done by means of electricity there are three governing factors, i.e., the electromotive force, the resistance, and the electrical current. The electromotive force is measured in volts, and is technically spoken of as voltage. The resistance is measured in ohms; the current in amperes, and it is spoken of as having a

certain amperage. The relations that exist between these factors are expressed in Ohm's law, upon which and the simple deductions therefrom are based nearly all calculations in electrolytic work.

"Ohm's law, briefly stated, is this: "The resulting electrical current is equal to the electromotive force divided by the resistance." In other words, the electromotive force (electrical pressure created by the dynamo) causes the flow of the electrical current. The latter is directly proportional to the former. The resistance opposes the flow of the current. The latter is, therefore, inversely proportional to the former. The electrical power is the product of the number of volts multiplied by the number of amperes of the current. Its unit is called a watt.

"From Ohm's law it follows that to double the resistance halves the current, the electromotive force remaining constant. Or if with the doubled resistance the current is to remain constant, the electromotive force, and therewith the power, must be doubled. This applied to electrolysis means that with the same current we can deposit an infinite quantity of copper, but that the power necessary must ever increase proportionally to the resistance.

"Another important deduction from Ohm's law is the following: When through a given resistance the current is required to be doubled, the power must be increased four times; or in general, the resistance remaining constant the power increases proportionally to the square of the current. This applied to a practical example means that if from a given number of depositing tanks we wish to double the output of copper by doubling the current, we must increase our power four times; or should we wish to quadruple the output the power must be increased sixteen times. We therefore encounter the economic problem: Is it more advantageous to double, quadruple, etc., the capacity of an electrolytic plant as to number of tanks or to increase

four times, sixteen times, etc., the power in order to increase the output proportionally to the former? The first is a single investment, the second a permanent expense.

"The most important laws in direct relation to electrolysis are those of Faraday, who showed that a given quantity of current will always deposit the same quantity of a given element, and that the elements are deposited, or their compounds decomposed, proportionally to their equivalent weights, e.g., hydrogen 1, oxygen 8, copper 31.7, silver 108, etc.

"It has been demonstrated by careful experiment that one ampere of current will deposit 1.18656 g. of copper in one hour, which can be translated for technical purposes to mean that one ampere of current should deposit 1 oz. of copper in 24 hours. It is, therefore, an easy matter to keep a record of the efficiency of a plant, or to detect leakages of the current, by measuring the current, weighing the deposited copper, and comparing the latter with the theoretical quantity required. The quantity of current, i.e. the number of amperes, flowing through a certain unit-surface is termed the density or intensity of the current. The greater the density of the current the greater will be the rate of deposition of the metal on a given surface. In order to deposit pure copper it is essential to have a constant current density. The copper is, however, deposited in satisfactory condition only when the current density is maintained within certain limits. The usual density employed in the United States is 10 or 12 amperes per square foot.*

"Joule found that an electrical current passing through a conductor generates a certain quantity of heat, and he established what is known as Joule's law, namely, the quantity of heat developed in a conductor is proportional to the resistance of that conductor and to the square of the current density. When heat is thus produced in the conductors and the electrolyte it is a waste of power.

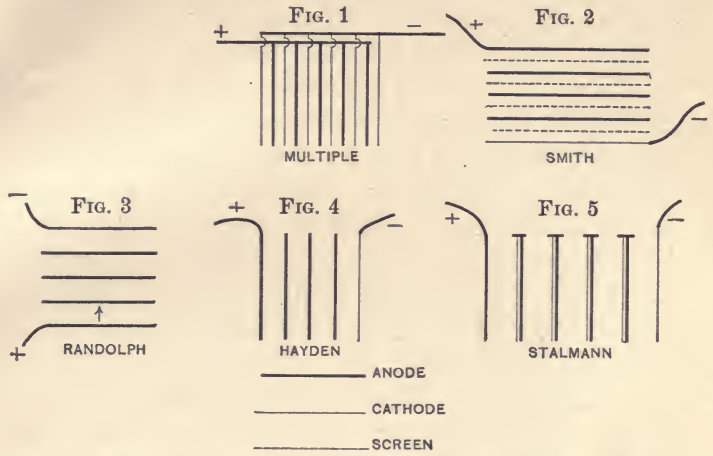
* Now 12 to 15 amperes.—*Note by Author.*

"The copper plate in the depositing tank which receives the current, and is dissolved by the latter's action, is called the anode plate. The plate on which the deposition of the metal takes place is called the cathode plate, and the two are the electrodes. The solution in which they are immersed is the electrolyte.

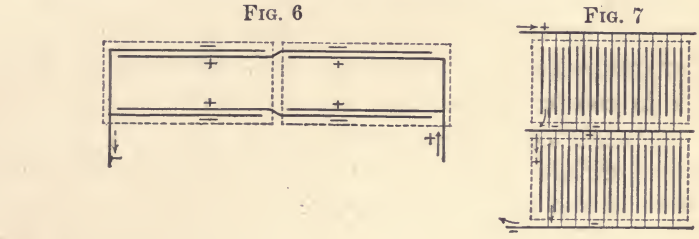
"In an electrolytic copper refinery the current must be adapted to the given condition of electrodes and tank arrangement, or the latter to a given current. For example, if with a given current, say 1000 amperes, we wish a current density of 10 amperes per square foot of anode surface, and our anode plates have a surface of 10 sq. ft., it is necessary to let the current pass through 10 such plates connected in multiple. These would be placed in one tank with, say, 11 cathode plates, through which the current would pass into another tank of the same description, and so on. Tanks are thus connected in series. As their number increases, the voltage necessary to carry the current through them must increase proportionally. With the increase of voltage the danger of loss of current through leakage increases. There must, therefore, be a limit to the number of tanks connected in series. The highest voltage in present practice is about 180.

"The lower limit of a series is, of course, a single couple, one anode, and one cathode, with an electrical pressure of a fraction of one volt, the exact value depending on the distance between the electrodes, the density of the current, the character of the electrolyte, and the composition of the anode. In actual practice the voltage between plates varies between about $\frac{1}{6}$ and $\frac{1}{3}$ volt, according to the system employed. The voltage necessary to decompose copper sulphate and to deposit the metal on the cathode is theoretically 1.16 volt. With a soluble anode this is counterbalanced by the energy evolved in the formation of copper sulphate on the anode surface."

Comparison of Methods.—There are only two systems of electrolytic copper refining proper now in use, which differ chiefly in the mode of arranging the electrodes. They



Arrangement of Electrodes in the Different Systems of Refining.



Various Arrangements of Conductors in the Multiple System.
(The dotted lines indicate the outlines of the tanks.)

are known as the multiple and the series processes, the latter being employed in only two or three works, and the use of the Smith, Stalmann, and Randolph arrangements of electrodes having been discontinued. The scheme of

arrangement of electrodes and conductors in these various systems is indicated in the subjoined cuts, Figs. 1 to 8, inclusive, from which it will readily be gathered that vertical electrodes are employed in the Multiple, Hayden, and Stalmann processes, and horizontal electrodes in the Randolph and Smith systems, and that the latter is the only one in which screens to prevent the anode slimes from falling on the depositing copper are interposed between the plates. A few other processes, such as the Elmore, Emerson, and Cowper-Coles methods for producing tubes and other shapes, and Thofehrn's direct method of producing wire bars, are more properly shape-producing than true refining processes, and will therefore not be treated in this monograph, excepting in so far as they have attained practical prominence in copper refining. Neither will I discuss the Marchésé, Hoepfner, Siemens and Halske, and Keith processes, as they apply particularly to ores and matte and not to crude copper, and have not, it appears, proven profitable.

Those who have to select a refining process and have to operate electrolytic works, must consider the following facts in comparing the two systems of refining:

The series or Hayden system, as developed in the United States, differs from the commonly employed multiple system in the following respects:

1. Special cathodes, as in the multiple system, are not necessary, one side of the anode plate serving as cathode.

2. The anodes, excepting the first and last, are not connected to copper conductors, the solution alone serving to conduct the current, and the plates are placed in series.

3. Much larger tanks than those used in the multiple system are employed, the size at the Nichols Works, Brooklyn, being 16 ft. long, 5 ft. deep, and 5½ ft. wide.

4. The anodes used are either ¼ or ⅜ in. thick and are longer, thinner, and narrower than multiple anodes. They

are straightened by rolling at the Baltimore Hayden plant and hammered straight by hand at the refinery of the Nichols Company. At the latter works six anodes, each 4.5 ft. long, 10 in. wide, and weighing 65 lbs., are suspended abreast in a tank and form a row, while at the Baltimore Copper Works a row is made up of two anodes, a lower and an upper plate, held at each side in a grooved slide. The rows of anodes are placed 0.5 in. apart at Baltimore and 0.8 to 0.9 in. apart at the Nichols plant, and the drop in potential between any two rows is therefore as low as one-ninth of a volt.

The series system is used only by the Baltimore Electric Refining Company and the Nichols Chemical Company, a serious drawback being found in the large quantity of scrap copper produced with this process, which averages about twice as much as in the multiple process.

With the same solution, it is obvious that the voltage required per tank will depend upon the area of the plates, the distance of the plates apart, and the number of plates in series. In a series tank, therefore, the electromotive force must be many times greater than the electromotive force required in a multiple tank; and where many plates are arranged in series, the voltage required to maintain a given density of current is very great and leads to short-circuiting and other evil consequences, unless great care is constantly exercised.

As Barnett states in Peters' "Modern Copper Smelting," one must also take into account that the slimes, as they collect on the bottom of the tank, form a large conducting plate. If the electromotive force is sufficient to overcome the resistance between the bottom of the electrodes and the layer of slimes, the current will flow partly through the electrodes and partly through the slimes, in amounts inversely as the resistance of the two routes. Owing to the lessened density of current at the electrodes

this will be manifest in a diminished output per tank. That such short-circuiting occurs is proved by the fact that more copper is deposited on the end electrodes in the series than on the intermediate plates, for there the currents will recombine to a greater density per square foot of depositing surface than elsewhere in the tank. Likewise the observed rapid concentration of copper in the electrolyte of series processes is probably largely due to the combined chemical and electrolytic solution of the anode scrap in the slimes.

Series tanks are constructed of slate, or of wood, lined with some acid-proof non-conductor, as a lead lining manifestly could not be employed in the series system. Slate tanks, although durable, are very expensive, as the average cost of slate for electrolytic vats in the United States is about 40 cents per square foot of $1\frac{1}{4}$ in. thickness in lengths not over 5 ft.; but the cost advances at the rate of 5 cents per square foot for every additional foot in length.

Wooden tanks, although cheap (they usually cost about $30 each), soon become efficient conductors and lose considerable current by short circuits around the sides of the tanks and leakage to the ground. This is partly because the penetration of the acid sulphate of copper cannot well be prevented in tanks constructed of wood, even if lined with tarred felt and asphalted. The older the tanks the more subject are they to these disorders. That is one of the reasons why, in the series system, only about 90% of the theoretical deposit is obtained from a given current, even with comparatively new wooden tanks, and that the average efficiency falls far below this figure.

In two given plants having equal cathode surfaces and using equal current densities the multiple system requires only about one-half the anode copper used in the series system. As refineries tie up between several hundred and several thousand tons of copper each, the factor of

interest on one-half of this is not to be disregarded. In series processes, therefore, the anodes are made thin, so as to obtain the maximum depositing surface with minimum weight of anodes. But the greater care which must be exercised in preparing thinner anodes, and the need of more frequently renewing such anodes than the thicker anodes used in the multiple system, entail fixed charges which about balance the saving in interest effected by using the thinner electrodes.

Maurice Barnett ably reviews the question of the relative expense of operating the two systems of refining in Peters' "Modern Copper Smelting," and reaches the following conclusion:

"In order to compensate for the extra copper used in the series system, it is the rule to economize in tanks and solution by arranging the electrodes closer together than is done in the multiple system. With electrodes close together there is the possibility of sprouting and short-circuiting, unless the current is maintained of uniform density over the entire surface of the electrodes. Hence arises the necessity, in series processes, of working the anode copper up to a point where it is uniform and following this by poling.

"In the multiple system the copper does not necessarily have to be improved and poled, although this procedure is not uncommon. At the Boston and Montana Company's Works at Great Falls, Mont., the anodes are cast direct from the converters, thus saving the entire cost of remelting and refining the anode copper inherent in the series system. To neutralize the inevitable consequence of unequal corrosion following from such a procedure, it is customary to place the electrodes from two to two and one-half inches apart. There is not then the necessity for maintaining a uniform density of current over the entire surface, this inequality of density in the rougher plates

being overcome by changing the cathodes rather more frequently than the anodes. Short-circuiting from sprouting is thus prevented and the inequality of density of current neutralized. In the series system, 'stripping' the deposit cannot be economically practiced until the tank, as a whole, is ready to be emptied.

"Of course the use of less pure copper in the anodes in the multiple system tends to make the electrolyte impure and increase the cost of refining by necessitating renewals of the electrolyte. This is true, however, only where no effort is made to keep the electrolyte free from the impurities that enter it from the anodes. At first sight it would appear as if the extra expense in preparing the anodes would be justified, because smoother and thinner electrodes can be brought closer together—say to one-half the usual distance allowed in the multiple system, resulting in a reduction of the resistance between electrodes and a doubling of the output per horse-power of mechanical energy expended.

"While the output is undoubtedly increased in this way, it cannot at best be more than double the output under the multiple system save where the anodes are rolled plates. Here the resistance between electrodes is as low as one-third that between electrodes in a multiple tank. The expense, however, of rolling the plates and the greater cost of stripping indicate that economy cannot be effected along these lines.

"In a general way it may be stated that the cost of improving and poling anode material exceeds the saving resulting from increased output per horse-power of mechanical energy expended. The multiple system, moreover, is free from the costly process of stripping the deposited copper from the anode scrap. This separation is frequently so difficult a matter that the deposited plate is often thrown back into the blister furnace along with the rest of the scrap.

"Furthermore, the cost of maintenance of plant is greater in the series process, owing to the fact that the life of the tanks, when made of wood, is limited to about four years. Series arrangements gain slightly from the circumstance that there is less loss of energy in the conductors than in the multiple system, where there is always a consumption of about 5% to 8% of the mechanical energy of the circuit. Where coal is cheap, this is not very important. The interest charges on the plant are also slightly in favor of the series system. This favorable factor of the latter is offset by heavier cost of renewals and larger interest on stock. The series system is free from the expense of making cathodes, inherent in the multiple system, but is still subject to heavy charges for stripping, amounting to four times that of making cathodes.

"Balancing these various factors as well as is possible in two works operating under the same conditions of cost of labor and fuel, there is a saving in the operating expenses, in using the multiple system, of nearly $2 per ton of refined copper. This difference is susceptible of greater increase if the refinery is run as part of a converting establishment; for since anodes may be made direct from the converters, the expense of making them in the reverberatory, amounting to from $2 to $3.40 per ton, is altogether avoided.

"In general, the greater first cost of works using the multiple system lies in the extra expense of the tank conductors and plates for making cathodes plus about one-half of the value of the lead lining of multiple tanks plus one-third of the value of the steam and power plants. However, in spite of its larger first cost, the multiple system is, undoubtedly, susceptible of greater economy than is possible under series arrangements, as is shown by its adoption, after costly and exhaustive experiments, in works where the series system was formerly used.

"To sum up the preceding points, the current efficiency of the multiple process averages 95% as against 90% for the series process under similar conditions; much less copper is held back in the multiple than in the series system, and the relative cost of operating it is probably less by nearly $2 per ton."

Efficiency of Refining Plants.—Attention should be called to an important point sometimes overlooked by refiners, namely, their frequent waste of power, or the low energy efficiency of certain copper works. While the current efficiency of these same works, or quotient of the amperage employed for a given output divided by the theoretical amperage required to deposit the same amount of copper, may be as high as 90% or 95%, their energy efficiency, or quotient obtained by dividing the energy or current consumed in doing useful work by the total energy furnished by the dynamo, is sometimes only 30%, and in the average refinery it does not often exceed 65%.

The loss of energy is due partly to bad metal contacts and short-circuiting and partly to the use of voltages much in excess of those actually required to overcome the resistance of the solution and of the metal conductors. These facts show how important it is in electrolytic refining to exercise close supervision, and how its absence is often paid for in heavy waste of energy or by its equivalent value in coal or money.

Stock of Metal in Refining.—It is interesting to note the great reduction in recent years of the stock of metal required in copper refineries per unit of output.

Recognizing the disadvantageous features of the electrolytic process of refining copper to be, 1, the large cost of plant; 2, the constant attention required to be paid to the process; 3, the comparatively large amount of covered space necessary; and 4, the continuous period of time during which a considerable stock of metal remains

unproductive of interest, refiners turned their attention chiefly toward the last as offering the greatest field for improvement. Their efforts in this direction have been eminently successful, especially in the United States.

Fifteen years ago it was not at all uncommon for copper refineries here and abroad to require 75 to 100 times as much copper as was daily produced in their electrolytic plants to stock their tanks for regular work. Subsequently improvements of various kinds brought this amount down to 50 or 60 tons for every ton of copper produced; yet to-day, in several cases, only 15 to 20 tons are required per 1 ton of output.

This great improvement, which has so largely reduced the cost of copper refining, is due chiefly to the employment of an increased density of current, resulting in more rapid working and a greater output with the same stock of copper and solution. Formerly current densities of 2 to 4 amperes per square foot of cathode surface were commonly used in refining; yet to-day they average from 12 to 16 amperes in the United States, and in one or two works current densities of as much as 35 or 40 amperes are employed. The quantity of copper undergoing treatment with the same output of metal is thus correspondingly reduced to one-fourth, and in some cases less than one-fifth, of what it was formerly. One must not overlook the fact, however, that there are important limiting factors to this tendency to increase the current strength and thereby reduce the stock required. In the first place, the maximum allowable flow of current and the minimum permissible rate of circulation and speed of purification depends on the richness of the anode in precious metals and on its contents and that of the solution in arsenic and other impurities. If large quantities of these are present, a high-current density, which is of course accompanied by a high rate of anode dissolution and an impure electrolyte, would

carry part of the silver and arsenic to the depositing copper, chemically or mechanically, and thus reduce its purity and its electric conductivity, if special means or prevention are not adopted. With very pure crude copper, on the other hand, current densities as high as 30 and even 40 amperes may be used.

In refining plants treating arseniferous copper bullion rich in precious metals, the average electric current is not over 8 to 10 amperes per square foot (counting both sides of the cathode plate), while those producing electrolytic copper from a good or extra good quality of copper bullion may employ three or four times this current density.

Under modern conditions, a 15-ton plant does not usually require stocks of more than 200 to 300 tons of copper to be placed in course of treatment, while 600 to 900 tons were formerly considered necessary for a daily output of 15 tons. With plants of any given capacity much smaller tonnages in stock are considered adequate nowadays than in former times.

Besides the total stock of copper in the tanks, however, there is generally tied up from 50% to 100% of this quantity in the form of blister copper for making anodes, main conductors, new anodes ready for immersion, residues of old anodes, solution and stock of refined copper.

It appears that the total amount of copper in process of treatment—stock, solution, and conductors—averages 10 to 20% of the yearly output of our electrolytic copper works, as against a permanent stock of 30% to 40% formerly.

Other things being equal, this means a great reduction of the period of time during which the stock of metal remains unproductive of interest, or an equivalent decrease in the amount of working capital required for a given output in refining copper.

Sampling and Assaying.—With regard to the sampling of blister copper and anodes, E. Keller proposes the follow-

ing improvement: It has been found that samples taken from different portions of anode plates and pigs of blister copper are apt to vary considerably in their percentages of gold and silver, as well as base metals, owing to their segregation in cooling, and that the common method of securing samples by drilling, punching, or chipping often leads to erroneous results. A more rational and satisfactory mode of sampling is to take the sample when the copper is in the furnace and after the charge has become thoroughly mixed, and either to pour a shot sample from a ladle in which the whole metal is liquid or to cast a sample plate the thickness of which is small compared to the other two dimensions, and to drill or punch a sample from this plate.

With electrolytic copper, not only different plates from the same tank, but different portions of the same plate may show a different composition, and the sampling is only satisfactory after the cathode plates are melted down and the furnace charge has become thoroughly mixed.

Refiners have unfortunately not yet agreed upon standard methods of assaying and analyzing blister copper, furnace slags, anodes, cathodes, slimes, and refinery solutions, and to describe all the methods in use at the various plants here would require more space than I have now at disposal. The reader is therefore referred to descriptions and discussions of the various methods that have appeared in the *Engineering and Mining Journal*, Dec. 16, 1899, and *The Mineral Industry*, vol. ii, pp. 276–277; vol. viii, p. 187; vol. ix, pp. 226–229, and vol. x, p. 228.

The Chemistry and Physics of Refining.—Prof. M. Kiliani, in 1885, was the first investigator to call attention to many of the following chemical and electrochemical reactions involved in copper refining.

With a normal current density of 2 amperes per square foot and an electrolyte containing 150 g. blue vitriol and

50 g. sulphuric acid per liter, the cuprous oxide contained in the anode because of its poor conductivity remains unattacked and accumulates in the anode residue or slimes. By a secondary reaction, however, it gradually dissolves and thus reduces the acidity of the solution and increases the copper contents of the latter.

Silver, gold, and platinum, unless present in considerable quantities, and unless the solution is not of normal strength, are completely recovered in the tank residues, barring 0.2–0.3 oz. Ag per ton found in almost all cathode copper. If the solution becomes neutral, silver is dissolved and apt to be deposited on the cathode. The solution of the silver is checked by the addition of salt or a small beakerful (say 300 cc.) of hydrochloric acid to the contents of every electrolytic tank.

It has not yet been definitely settled whether the arsenic in the anode is present chiefly as metal or as arsenate of copper. In the former case it passes into solution during electrolysis as arsenious acid, and arsenic is not deposited until the electrolyte has become saturated with this acid. When arsenate of copper is found in the anode, this salt, being a non-conductor of electricity, is not altered in its composition, and forms part of the residue. In the course of time, however, arsenious acid is dissolved as a secondary result of the action of the free sulphuric acid of the electrolyte, and a certain amount of green, insoluble, slimy arsenite of copper is eventually formed. This secondary formation of arsenious acid can be diminished by frequently removing the slime film from the anodes, i.e., lifting the latter out of the tanks and washing off their adhering slimes into a special receiver. From a neutral bath or a solution containing an insufficiency of copper, arsenic is deposited on the cathode with the copper. Some American refiners add 0.5% and others up to 20% of ammonium sulphate to the electrolyte to hinder as much as possible the electro-

deposition of arsenic with the copper. The limit of arsenic allowed in the cathode copper for making wire bars is understood to be 0.002% at the Balbach Works and 0.001% at the Nichols Refinery.

Antimony, if found as metal in the anode, partly dissolves at first, although a portion of this dissolved antimony may eventually precipitate as a neutral salt, and partly forms an insoluble basic sulphate of antimony, which coats the anode. In the course of time antimonious acid is formed, on account of the secondary action of the free sulphuric acid present. Antimony is not electrolytically deposited on the cathode as long as the solution is nearly normal in composition (containing 5% to 6% free acid and 15% to 20% bluestone), even if the electrolyte is so saturated with antimony that its basic salts begin to separate. At the worst a little basic antimony compound may be mechanically deposited on the cathode and form a black coating containing both copper and antimony. Antimony is apt to deposit with the copper and cause the latter to become dull colored, brittle, and to form needle-like projections whenever the solution becomes neutral, but if the solution contains an insufficiency of copper, antimony is invariably thrown down on the copper, even when considerable free acid is present.

Iron in the anode dissolves more readily than the copper and forms ferrous sulphate, which in time is partly oxidized to ferric compounds. These are produced freely and directly whenever the density of the current reaches 1300 amperes per square meter. "Sprouting" of the cathode is produced, if iron is allowed to replace copper in the electrolyte, until there is but 2 g. of copper present to the liter of solution.

Copper deposited with a weak current from a neutral solution, even if the latter is free from impurities, is often so brittle that it can be readily pulverized. This is due

to the fact that the copper contains cuprous oxide. Of course the neutralization of the electrolyte also decreases the conductivity of the solution, so that its resistance with anodes 5 cm. apart, for example, may be raised from, say, 0.1 volt (normal) to 0.25 volt. A weak current is not able to completely decompose the copper sulphate into Cu and SO_4, so that some Cu_2O is deposited with the copper. This deposit of Cu_2O decreases with increasing current strength up to that point at which the current is strong enough to throw down absolutely pure copper.

In acid solutions the cuprous oxide of the cathode is decomposed by a secondary action, while in a neutral electrolyte it remains on the cathode. Roessler's hypothesis may explain why certain refiners associate a green solution with bad cathode copper, good copper being deposited from the same solution, as soon as it changes its color from green to blue. Roessler believes that under certain conditions metallic copper reduces an acid solution of cupric sulphate and forms cuprous sulphate, which is subsequently oxidized by the air to cupric sulphate. The quantity of copper so dissolved increases with the rapidity of the circulation, i.e., the more the electrolyte is exposed to the atmosphere, and with the diminution of the density of the current. The more thoroughly the circulation is kept up, the purer, more finely crystalline, and more flexible will be the deposited copper, even with nearly pure solutions and under otherwise normal conditions.

Tellurium and selenium, which are frequently present in anode copper, probably as telluride and selenide of silver or copper, have but little effect, it seems, on the purity of the copper deposited.

It is, of course, very important that the acidity of the electrolyte be determined daily and that the normal composition of the electrolyte be maintained.

Since the time of the appearance of Kiliani's masterly

essay, the accepted views of some of the reactions involved in electrolytic refining have slightly changed. Credit is due Dr. Emil Wohlwill for his recent work in connection with observations of such reactions and their explanation, as given in the late revised edition of Borcher's "Elektro-Metallurgie," pp. 198–206. Wohlwill finds that Kiliani underrated the importance of the presence of finely divided metallic copper in the anode residue. Such copper, separating out from anodes that are free or comparatively free from impurities, appears of a dark reddish or rich red color as long as discoloring impurities are absent. The amount of such finely divided metallic copper (termed anode powder) produced depends chiefly on the current density used, and varies according to the following principles: 1, the less the current density the greater the quantity of powder forming in a given time; 2, with the same current density the amount produced increases with an increase in the acidity of the electrolyte; and 3, under otherwise similar conditions, the quantity of anode powder formed varies inversely as the duration of uninterrupted electrolysis.

The following hypothesis may serve to explain the above phenomena. During electrolysis a small amount of cuprous sulphate forms at the anode along with the cupric sulphate, only to decompose again in contact with the anode or in its immediate vicinity into copper and cupric sulphate, somewhat as copper, dissolved in a hot solution of cupric sulphate, separates out as metal when the solution is refrigerated. But as the current density decreases, the number of univalent ions forming along with the bivalent ions increases, and consequently the greater the amount of anode powder produced.

In Wohlwill's opinion, the separated copper powder in contact with the unattacked copper of the anode acts like an electro-negative or less soluble metal and consequently protects the copper surface it covers. The electrolytic

action is thus restricted to the uncovered portions of the anode and therefore to a decreasing area, which means that the current density increases and thus diminishes the number of univalent ions forming in a given time. This hypothesis accounts for the fact that the excess of the loss in weight of the anode over the increase in weight of the cathode varies inversely as the time during which electrolysis is continued. Moreover, it explains why the anode surface becomes rough or pitted, as chemical solution alone without the formation of this protective metallic powder would naturally tend to keep the anode surface smooth. Smooth surfaces are only secured when cuprous ions are produced in negligible quantities, as when high-current densities are maintained. Additional proof of the correctness of the above hypothesis lies in the absence of any such anode powder in the electrolysis of chloride solutions with copper anodes.

The separation of the red powder of metallic copper at the anode in sulphate solutions furnishes a valuable means of detecting the purity of the copper that is being dissolved; for even very small amounts of impurities produce a darkening in color of the separated anode powder and anode itself, so that anodes of all sorts of copper not previously refined electrolytically, or of copper deposited so carelessly as not to avoid the codeposition of such impurities as arsenic or antimony, invariably turn very dark. Hence one may easily determine if the electrolytic process is being properly carried on by periodically removing samples of the cathode copper and suspending them as anodes. With the low-current densities in vogue at the Hamburg Refinery the anode residue naturally carries considerable finely divided metallic copper. The latter product is probably the chief cause of the gradual decrease of the acidity of the electrolyte and increase of its copper sulphate contents, as it readily dissolves in dilute sulphuric acid in contact with air to

copper sulphate. This increase of the bluestone contents and decrease of acidity is therefore especially noticeable in installations in which air is used to circulate the solution and equalize its density, and is not, in Wohlwill's opinion, due chiefly, as was formerly thought probable, to the chemical action of the dilute sulphuric acid on the cathode copper. At Hamburg fully 2% of the copper contents of the anodes are recovered annually in the form of blue stone.

Another regular constituent of the anode slimes of refineries is chlorine combined with copper. Whenever the water used in electrolysis contains large quantities of chlorides, the anodes are covered with a white coating of cuprous chloride, which darkens in time through the action of the air to dirty green-colored oxychloride. Eventually this is further decomposed by the sulphuric acid of the electrolyte and contributes also to the increase of the bluestone contents of the latter. Copper electro-deposited from chloride solutions and salty river-water always contains chlorine when low-current densities are employed. It may then be noticed, when cathodes are arranged as end plates, that the backs of the latter become covered with white or green cuprous chloride. The latter sometimes adheres so firmly as to occasion considerable trouble in the refinery and necessitate the partial resolution of such plates, or the substitution of an anode for the cathode at the ends of such tanks, to distribute the current density uniformly over the cathodes, and thus obtain good electrolytic copper on all of them.

Wohlwill found that the copper deposited on lead strips, hung as cathodes alongside of the regular cathode sheets, as a means of checking the changes in the electrolytic product, when stripped off weekly was very brittle immediately after starting a tank system with an electrolytic solution containing salty water, and that the deposits made later were less and less brittle. After running for a few

weeks the deposited copper was so tough that it could be bent back and forth twenty times without breaking. Determinations then made proved, according to Dr. Wohlwill, that the brittleness of the cathodes varied directly as the chlorine contents of the latter and of the solutions.

In my opinion this statement requires modification, at least in so far as its bearing on American practice and conditions is concerned, for refiners in the United States find, in starting deposition from a normal acidified copper sulphate solution free from hydrochloric acid, that the starting sheets are generally brittle, and that good tough starting sheets may be secured by adding a small pitcherful (about 300 cc.) of hydrochloric acid to each tank. Dr. Wohlwill also came to the conclusion that it would not be good practice to employ an electrolyte free from chlorides. He encountered great difficulty for many years at the Hamburg Refinery, because periodically the deposited copper became covered with octahedral crystal aggregates. Although these crystal groups, often as much as 10 cm. long, consisted of pure copper, practical considerations demanded taking means for preventing their formation or their prompt removal, naturally at the cost of much labor and expense, and often of serious delay in the contract time of delivering cathodes. It was found that these troubles reached their maximum when the water used as the basis of the electrolyte contained the least salt, say in January, and were least when the solution contained the most salt, as in July and August. The addition of sodium or magnesium chloride in the first case immediately improved matters. However, it did not entirely prevent the formation of needle-like projections, so that a satisfactory explanation of the above phenomenon is still wanted. The peculiar discovery was made later that a solution of the above difficulty lay simply in periodically interrupting the process of electrolysis. By stopping the action of the current in

all the tanks for, say, half an hour during each day, Wohlwill found that the sprouting of the cathodes was diminished to such an extent as not to require any further special attention, and has now adopted this practice in the Hamburg Refinery.

As far back as 1886, Huebl determined experimentally that the tensile strength and hardness of electrolytic copper is not dependent on the concentration of the electrolytic solution, but increased with increased current density, and reached maximum values with an electrolyte containing 20% bluestone when the current density was 22 to 30 amperes per square foot. With the above composition of solution the highest elastic limit was obtained when the current density reached 10 to 15 amperes per square foot and the greatest toughness at 6 amperes per square foot.

Foerster and Seidel finally investigated the influence of temperature during the electrolysis of copper, and in 1889 published figures showing that they secured the toughest, finest, and most evenly crystallized copper when they heated the electrolyte to 40° C.

Woolsey McA. Johnson* assumes that ordinary copper anodes may be considered as being mixtures of pure copper and copper-silver alloys, cuprous oxide, and oxides of antimony and arsenic, or solutions of these alloys and oxides in pure copper, and states that, in his opinion, because the electrical resistance of copper-silver alloys and of the oxides is higher than that of pure copper, the silver alloy and oxides would tend to "slime" under normal conditions and thus tend to keep the solution in a pure condition. To explain these views, which have been more or less well recognized since 1885, when Dr. Kiliani's pioneer investigations were published, Johnson has recourse to the following known facts:

* Paper read at the meeting of the American Electrochemical Society, Sept. 16, 1902.

1. Every metal has a certain specific electrolytic tension or voltage depending upon its temperature, physical condition, and the solution in which it dips.

2. Every metal has a specific electrical conductivity.

3. These two properties are profoundly modified by alloying with other metals.

On these properties of the resulting alloys segregated in the anode depends the selective electrochemical dissolution.

Metals unite with one another to form alloys, in most cases with the evolution of heat, and the atoms are then united with a firmer bond. In other words, the free energy is diminished, and as the electrolytic solution tension is measured by the free energy of the metal, in normal solution of its ions, it also must decrease. The resultant product is harder and has less tendency to dissolve.

That most alloys of any two metals show a poorer conductivity than the mean conductivity of the metals composing such alloy, and in many cases than the conductivity of either metal alone, is well known. These facts have an important bearing, in electrolytic refining, in determining the behavior of alloys and oxides contained in ordinary copper anodes. For instance, if we consider a particle of silver-copper surrounded by pure copper crystals, the effect of the great difference in electrical conductivity is pretty certain to shunt the current around this silver-copper alloy and finally dissolve its copper backing. It then can be brushed off into the slime. This, of course, applies to all the alloys (and oxides) that have a low conductivity.

Arsenic and antimony, were they present in the anode as metals, would have a greater tendency to dissolve than copper, because of their high electrolytic solution tension. Fortunately for the electrolytic refiner, however, the larger portion of these elements are thoroughly oxidized, either

in the converter or reverberatory furnace. The copper is then brought to "set" in the refining furnace before casting into anodes if the copper is not cast into anodes direct from the converter, receiver, or the mixer. The heats of oxidation of arsenic or antimony being many times larger than that of copper, the oxides of the former metals are not reduced to any extent in the "poling" operation in the refining furnace as long as any cuprous oxide is left. Arsenic and antimony are thus present in oxidized anodes mainly as insulators, and as such pass into the slimes directly.

Treatment of Solutions and Making Bluestone.—The tendency of the electrolyte with long use in circulation to dissolve or carry in suspension impurities in dangerous quantities, so that its continued use would cause disturbance or the deposition of arsenic, antimony, bismuth, and other metals or of their combinations on the cathodes, i.e., the production of a copper unfit for electrical purposes, must be opposed either by regularly purifying the solution and continuing its use, or better, by withdrawing a portion of the electrolyte from the regular circulation system altogether, treating it separately and replacing the portions so withdrawn by an equal quantity of fresh and pure solution. In most works this purification or withdrawal of the solution does not occur periodically, but is carried out as one continuous operation, a certain portion of the electrolyte always being under treatment. Moreover, as the electrolyte also tends to become richer in copper sulphate than the standard fixed upon, this excess of copper must likewise be removed, either by depositing out the excess of metal in special tanks with lead anodes and very strong currents or recovering the copper as bluestone by crystallization. Both methods are commonly employed in the same refinery.

After the recovery of copper vitriol from the discarded

electrolyte, by concentrating the solution up to 38° to 42° B. and crystallizing out the contained bluestone, the crystals formed, if necessary, being purified by repeated solution and crystallization until of marketable purity, the impure mother liquors are treated for the recovery of the remainder of the copper, usually by precipitation with scrap iron, in which case the acid is usually wasted, or by such means as secure the sulphuric acid in addition.

The sulphuric acid may be recovered by evaporating down the foul solution until the basic salts of iron and copper separate out and withdrawing the supernatant sulphuric acid for use in treating silver slimes or in acid-parting of doré bars.

It is, I think, a rather dangerous practice to allow the impurities to accumulate, before regenerating the electrolyte, until the quality of the copper is jeopardized, as noted in one plant. A regeneration method that has given complete satisfaction is described in this monograph under the caption of the Kalakent Works in Russia. It consists, briefly, in neutralizing the sulphuric acid in the solution by passing it over dead roasted matte and through roasted copper ores, diluting and heating the solution to 50° C., and injecting compressed air through it, whereby the contained impurities are precipitated, aided by suspending anode scrap in the solution to completely neutralize the same and form copper sulphate. After the separation of the impurities the solution is concentrated and clarified in special tanks, and being now pure enough, is acidified and returned to the copper-depositing system for reuse as normal electrolyte. The excess of purified electrolyte which gradually accumulates with this regeneration method is worked up into bluestone as usual.

Several similar methods of purifying the electrolyte have been suggested, such as (1) filtration through a bed of copper oxide, and (2) oxidation with jets of air.

The method of purification believed to be in use at Anaconda consists in repeatedly passing the impure electrolyte through a filter of oxidized granulated copper, which precipitates part of the impurities, and in oxidizing the solution, now neutral and saturated with copper, by introducing jets of air. The oxidation is said to cause the partial precipitation of the iron and other impurities in the solution.

An analogous improvement in the mode of circulating the solution was introduced into the old Guggenheim Refinery. This is based upon the well-known action of Pohle's air-lift or of Siemens' "geyser-pump." It consists in blowing air under 3 or 4 pounds pressure into the electrolyte by means of lead pipes in such a way that solution is drawn from the bottom of the tank by a lower pipe and delivered into an upper pipe, to be discharged back into the tank through a large number of perforations in this upper pipe. The electrolyte is thereby subjected to the oxidizing influence of air-jets, whereby the precipitation of some of the impurities suspended in the electrolyte is facilitated and the latter is clarified. Many refiners believe that a large portion of the arsenic, antimony, silver, etc., found in poor cathode copper is not deposited from the bath electrolytically, but mechanically, by suspended impurities settling on the rough surface of the cathode. This is especially the case when high densities or cloudy solutions containing floating impurities are employed. The advantage of a rapid clarification of the electrolyte is therefore evident. At first the importance of the air circulation and oxidation system was much exaggerated, especially as regards the removal of the arsenic, and a claim was made that it would altogether obviate the necessity of the usual system of circulation and purification. Although such general statements were not justified, the fact remains that the air circulation, if assisted during two or three hours

in every twelve by the general circulation of the solution from tank to tank, gave better results than when the old system was used alone.

The recovery of the bluestone from the discarded electrolyte is often accomplished as follows:

The solution is first boiled in lead-lined tanks with granulated or scrap copper, steam and air being introduced by means of a Koerting injector, so as to neutralize the free acid and to increase the copper contents of the solution to the degree desired. It is then pumped up to the crystallizing tanks, in which bluestone is secured by allowing the copper sulphate to crystallize out, as the solution cools, on bands of lead suspended in the saturated solution. The mother liquor siphoned off contains most of the arsenic and antimony originally present in the electrolyte, together with some remaining copper. To recover the latter, the mother liquor is usually treated in special tanks with sheets of scrap iron. This metal first precipitates out the copper and then the arsenic, so that a black precipitate is finally secured, containing at times as much as 60% of metallic arsenic. The impure precipitate, finally, is melted and reduced down into arsenical copper bars, or occasionally utilized in the manufacture of compounds of arsenic and copper, such as Paris green.

At the Baltimore Copper Works the adopted method of preserving the purity of the main electrolyte consists in periodically withdrawing a fixed portion—say one-fifth—of the electrolytic solution for manufacture into blue vitriol and replacing it by fresh electrolyte, so as to keep the percentage of impurities in the circulating electrolyte down to an approximately constant figure. The composition of the solution, strength of current, and other factors of refining not being permitted to vary within large limits, it is comparatively easy to produce a nearly uniform quality of copper. The bluestone recovered is sold at a fair profit,

and the mother liquor from the blue vitriol works is finally treated with scrap iron to precipitate the last 2% or 3% of copper it contains.

A mode of treatment similar to the Baltimore process is employed at the Balbach Refinery. Here the standard composition of the electrolyte is kept up by periodically running off a portion and replacing it with pure solution. The impure liquid is then pumped to the vitriol works, in which sulphates of copper, iron, and nickel are recovered from the solution by a process of fractional crystallization, after which the mother liquor is boiled down to recover arsenious and sulphuric acid. If the electrolyte contains considerable antimony, part of it is said to precipitate as gray metallic antimony or as antimonious acid in the discharge launders.

From a consideration of all of the above-described methods, we reach the conclusion that a crystallizing plant for the recovery of blue vitriol, although bulky and cumbersome, is still considered a necessary adjunct to copper refineries. However, by diminishing the need of blue vitriol works of large capacity, and thus avoiding the excessive production of what is often a drug on the market, the adoption of the best methods described above by refining companies has certainly resulted in keeping down the cost of refining copper.

Ottokar Hofmann describes his important improvements in the method and apparatus for purifying foul solutions and making bluestone substantially as follows in *The Mineral Industry*, vol. x. As applied to foul refinery solutions, Hofmann's process begins in elevating the latter by means of a pressure tank, shown in Figs. 9, 10, and 11, to the purifying towers, the hard-lead pumps formerly used for handling copper solution having proved failures. On account of occasionally having to handle residues, the pressure tanks are in an upright position and are constructed

as follows: "The body consists of two cylindrical sections 4 ft. long and 4 ft. 6 in. in diameter, the bottom being of a spherical section of 2 ft. 3 in. radius and the top rounding upward to a height of 6 in. above the rim. The sections

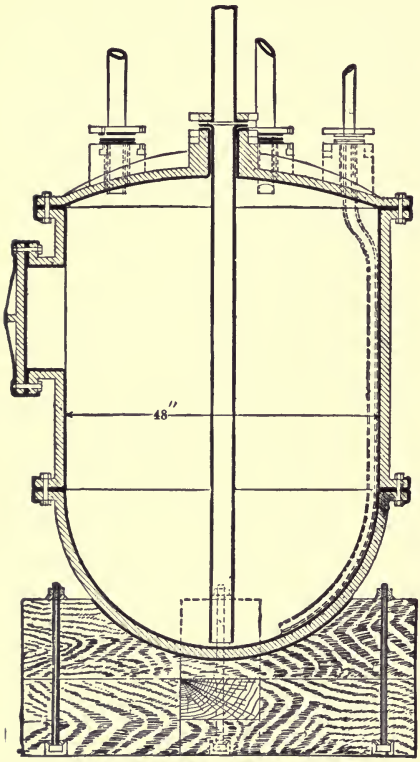


FIG. 10.—Section on Line *AB*.

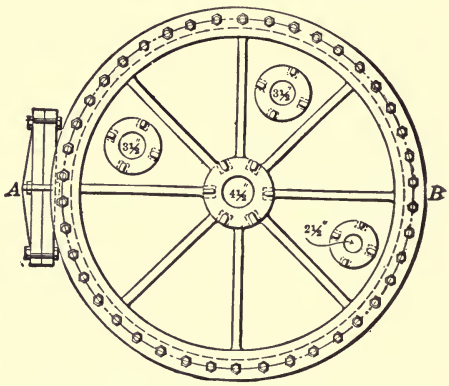


FIG. 9.—Plan showing Size of Openings.

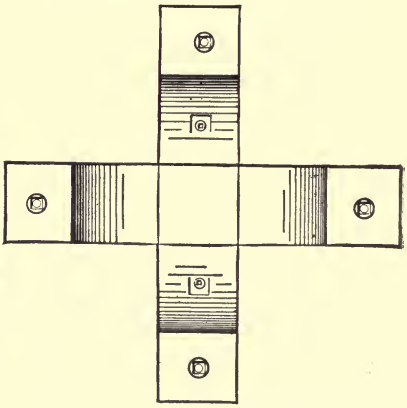


FIG. 11.—Plan of Supporting Frame.

FIGS. 9, 10, and 11.—Cast-iron Pressure Tank.

are tightly flanged, with a rubber gasket between. Four pipe connections are made through the top; the discharge pipe entering through the center passes nearly to the bottom and the filling pipe, air-inlet and air-outlet pipes are conveniently arranged around it. By proper connection

with the filling pipe and by the use of valves, one pressure tank is made to serve four receiving tanks. The upper cylindrical section is provided with a manhole, and the tanks are lined first with lead and then with wood to protect the lead from wear by abrasion. The air pressure required is from 40 to 50 lb. Fig. 9 shows a top view, and Fig. 10 a vertical cross-section of an upright pressure tank, while Fig. 11 illustrates the supporting frame. This tank is somewhat smaller than those used in the Argentine blue vitriol plants and has one cylindrical section instead of two. The general arrangement, however, is the same. The air inlet extends downward along the side, ending near the discharge pipe, in order to keep any residues near the outlet in a loose condition and prevent the pipes from clogging. For this reason it is advisable to have a small stream of air enter during filling. The residues are rather heavy and occasionally pack tightly around the discharge pipe in quite a thick layer, which, on applying the pressure, would be forced in this compact condition into the discharge pipe and the pipe leading to the purifying towers, causing them to become clogged.

"The purifying or refining towers, as shown in the attached dimensioned sketch, are made of California redwood, which makes an excellent material to resist the action of hot cupric sulphate solution. They are 9 ft. in diameter at the bottom and constructed of staves 16 ft. long and 4 in. thick, which are well hooped with round iron; the bottom and top are flat. The towers are firmly fastened to a strong wooden trestle, which in turn is anchored to a concrete foundation. This construction is called for to guard against the oscillating movement of the tanks from the action of the contained solution, which is set in violent motion by the ascending air. Inside the tower, about 19 in. above the bottom, the 4-in. lead air pipe enters and is connected with a perforated 6-in. lead pipe which extends

diametrically to the opposite side and is closed at the farther end. Outside of the tower the air pipe extends upward to above the top of the tower, and thence downward to the discharge pipe of an air compressor. This arrangement is necessary in order to prevent the solution from flowing to the air pump. At the same level with the air inlet, the 4-in. discharge pipe enters, which is provided with a hard-lead valve placed close to the outside of the tower. At about the same level a 1-in. steam pipe enters for heating the charge. The lead steam coil formerly used has been discarded and the heating is now accomplished by direct steam. This change was necessary as the lead coil required frequent repairs, and, moreover, the heating effect of direct steam is much greater than that of a steam-heated coil. The solution does not lose in strength through the condensation of the steam, the evaporation, which is favored by the ascending air, fully equalizing the dilution. The top of the tower is provided with an 8-in. pipe for the escape of the vapor and air, and with a 4-in. pipe for charging the crude solution. An opening in the center supports a small hopper which is filled with roasted matte, and by lifting a cone valve the charging is kept under good control. By the action of the air and the cupric oxide of the roasted copper matte in the neutral solution, the impurities are oxidized and precipitated. The perforated cones, of which there were three in each tower for the distribution of the compressed air throughout the solution, have been replaced by a sufficiently large perforated pipe. This change simplifies the construction without impairing the efficiency of the tower. In charging the towers, room must be left for the increase in volume of the solution which occurs as soon as the air is supplied. A tower of the new type can be charged with about 5000 gal. of solution, and as three such charges can be refined in 24 hours the working capacity of one tower is 15,000 gal. per day. Eight of these

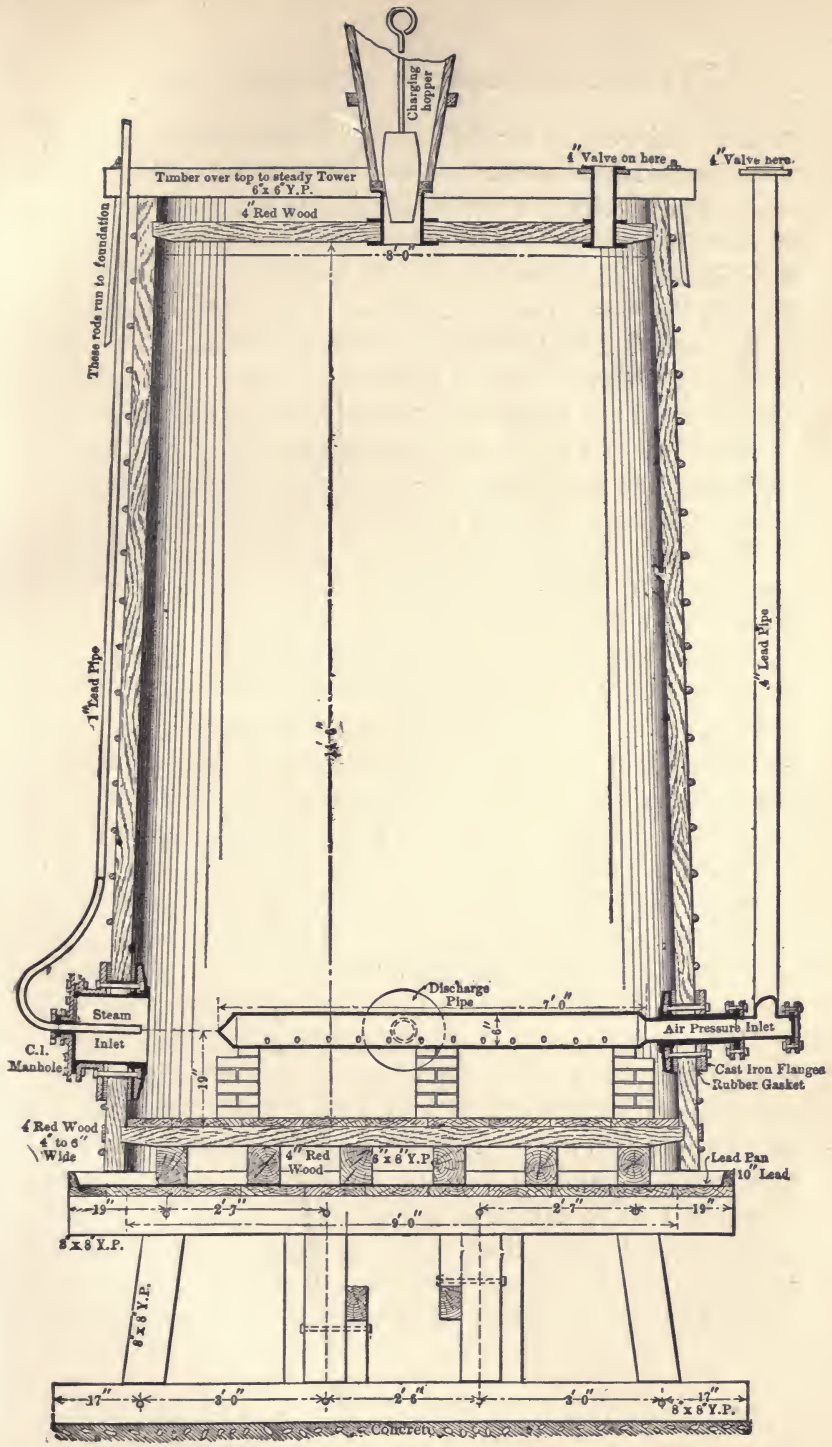


FIG. 12.—Hofmann's Tower for Refining Cupric Sulphate Solutions.

towers are in use at the Argentine plant. Fig. 12 shows a vertical section of a tower of the latest construction. The air-inlet pipe, which is horizontal within the tank, has only its lower half perforated to prevent the inflow of matte and precipitate. The steam pipe was formerly inserted direct through the wood, but as the latter became affected by the heat, it now enters through the manhole cover. A similar effect was noticed with the bolts which passed through the wood to hold the flanges of the manhole, air inlet, and discharge pipe. In the new construction these holes in the staves are cut much larger, and neither the frame nor the bolts are in contact with the wood. This is shown in the illustration. The two pipes are arranged in a similar manner. All iron parts on the inside of the tower are covered with heavy sheet lead.

"When the reaction is completed and the solution freed from impurities, the charge is drawn off and forced through a filter press. The tower residues, consisting mainly of precipitated iron, arsenic, antimony, and some undecomposed matte, contain also some basic copper sulphate. To remove the last-named substance the residues are treated in a stir tank with a 2.5% to 3% cold acid solution, which dissolves the basic copper salt, leaving the impurities unaffected with the exception of iron, which is acted on very slightly. The refined solution is conveyed to settling tanks from which the evaporating tanks are supplied.

"The evaporating department furnishes the crystallizing department with about 90,000 gal. of concentrated solution daily. To supply this amount an improvement over the old pan evaporators with under-fire or steam coils was requisite, and as vacuum evaporators could not be adopted, I have introduced an economical and effective evaporator at Argentine, which is illustrated in Figs. 13 and 14. The principles observed in the construction of this evaporator are the application of the hot furnace gases

direct to the heating of the solution and the almost complete utilization of the heat contained in them. The apparatus consists of a flat wooden tank with the exception of a 2-ft. space at the front end, which is made of steel, so that the wood will not be in too close proximity to the furnace. The tank is 65 ft. long, 12 ft. wide, and 2 ft. deep, and is lead-lined, the two ends having much heavier lead lining than the sides and bottom. It is traversed longitudinally by 13 six-inch lead pipes and rests on a wooden trestle-work of a proper height to correspond with the height of the furnace. At the furnace end in each lead pipe is inserted a 5-in. iron pipe 4 ft. long provided at the outer end with a flange. The iron pipes serve to protect the lead pipes from immediate direct contact with the red-hot gases from the furnace; they also make the connections between the lead pipes of the tank and the iron pipes of the furnace.

"The furnace is comprised of the fire-place *C*, the dust-chamber *D*, and the heat-distributing chamber *D'*. At a proper height in the wall of the distributing chamber nearest the tank are 13 openings, in each of which is inserted a short cast-iron pipe 5 in. in diameter, with a flange at the outer end. Each pipe is connected with its corresponding lead pipe in the tank by a cast-iron S-shaped elbow *Y*, which allows the introduction of the compressed-air pipe *E* for removing any accumulation of ashes in the lead pipes of the tank.

"An American underfed stoker is used for the slack-coal fuel, and affords practically perfect combustion, which is of great importance, as otherwise the lead pipes would soon become coated with soot and lose much of their efficiency to transmit the heat to the solution.

"The opposite end of the lead pipes in the tank are connected with the brick suction-chamber *O*, which in turn is connected by a galvanized iron pipe *R* with a suction

fan *P*, the gases being discharged into the underground flue *S*. This flue serves in common to collect the waste gases from 11 evaporators, and terminates outside the building into a brick chimney 40 ft. in height.

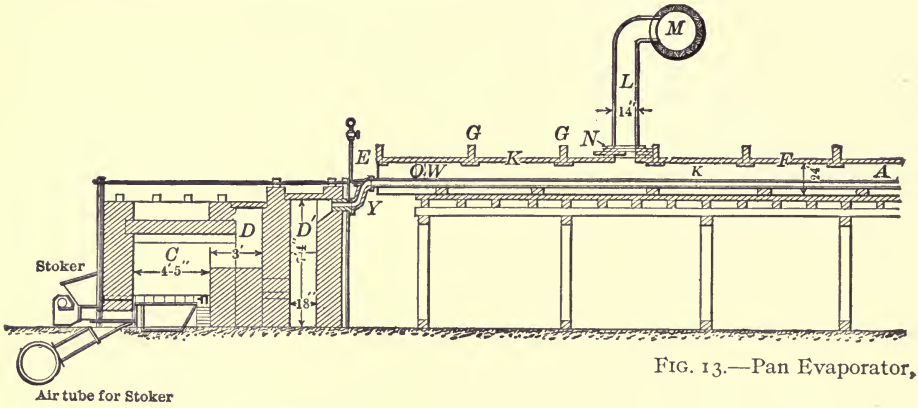


FIG. 13.—Pan Evaporator.

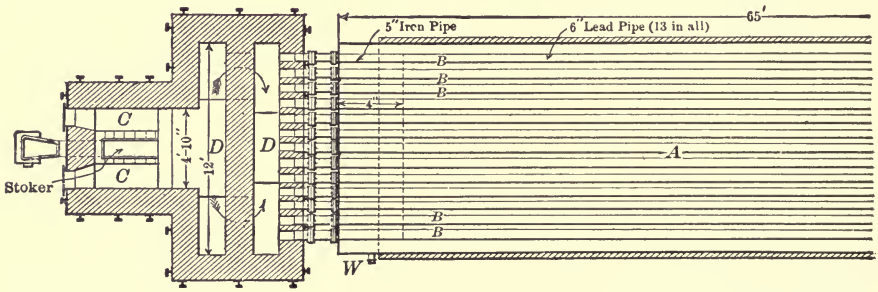
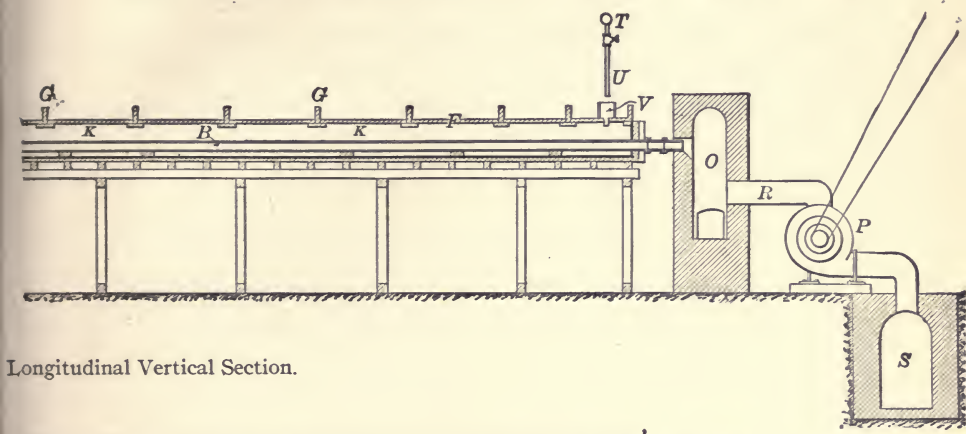


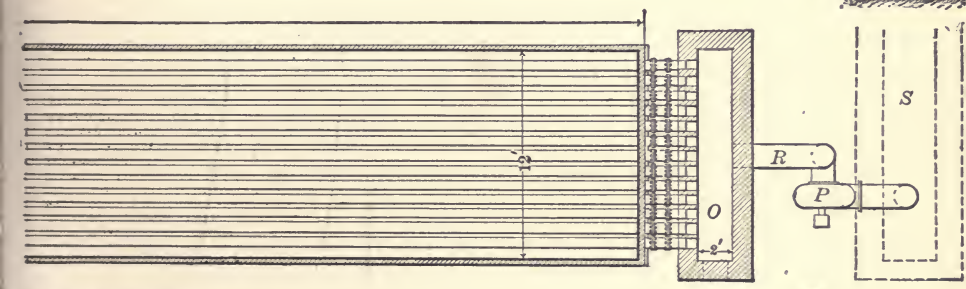
FIG. 14.—Pan Evaporator.

"The top of the pan is closed with a wooden cover and joists *G* are placed across the pan about 5 ft. apart, having cleats fastened to the lower side, as shown in Fig. 13. The spaces between the joists are covered with boards resting on the cleats and pushed close together, but not nailed, so that the whole or part of the cover can be easily removed. About 14 ft. from the front end of the tank is a 14-in. suction pipe *L*, connected with the main suction pipe *M*, which crosses all of the evaporators to remove the water vapors.

This main suction pipe is constructed of wooden staves kept tight by hoops. The suction pipe *L* was first made of lead, but by some unexplained chemical reaction it was destroyed after a few months of operation. Later a wooden



Longitudinal Vertical Section.



Horizontal Section.

tube was substituted, which was made in the same manner as the main tube. The latter is in connection with a large fan having the housing and wings of sheet copper and the shaft and arms of brass. This fan rapidly removes the vapor from each evaporating tank and by its use the building, even in cold winter weather, is entirely free from steam. A wooden stack serves for the discharge of the fan, and the strength of the exhaust is regulated by a wooden slide *N* inserted below the suction pipe *L*.

"Close to the end of the evaporating tank, and resting on the cover, is the lead-lined feed box *V*, from the bottom of which is a short pipe or nipple leading into the tank. The solution supply pipe *T*, which crosses all the evaporators, is connected with the large supply tanks and serves to convey the solution to each evaporator by downtakes *U*. The outlet of the evaporating tank is in the side near the furnace end about 4 in. above the hot-air pipe *B* (Fig. 13).

"The operation is conducted in the following manner: The pan is first filled to the level of the outlet with the copper sulphate solution to be concentrated, the fire is then started and the suction and stoker fans set in motion. The big copper fan is not started until the solution becomes hot enough to generate steam. During the operation the level of the solution is kept at the same height by the occasional addition of new solution through the feed box *V*. When it is found by test with a Baumé's scale that the solution near the outlet has attained the desired concentration, a continuous stream of weak solution is allowed to flow into the tank from the feed box, which starts a continuous outflow of concentrated solution through the outlet. The amount of incoming solution is regulated by frequent hydrometer tests of the solution at the outlet. The supply of fuel by the automatic stoker being very regular, the heat of the evaporator is very uniform, and once having adjusted the proper influx of the weak solution the outflowing stream will be found of quite constant concentration.

"The object in making the evaporating pan of this length is to utilize the heat of the fire-gases as much as possible. The glowing hot gases entering the tubes give off the main part of their heat to the solution within a comparatively short distance from the point of entrance and cause this portion of the solution to boil. In the passage of the gases through the tubes they gradually come

into cooler regions and are offered an excellent opportunity to give off more of their heat to the surrounding solution, so that when they finally leave the tubes their temperature is much below the boiling point of the solution. If the tank had been constructed of still greater length, say 100 or 125 ft., the gases would have left the tubes at a temperature about that of the surrounding air, thus completely utilizing the heat generated. With the 65-ft. tank, the pipes at the exhaust end of the tank can be touched with the hand.

"The greater economy and efficiency of this type of evaporator, as compared with one having a steam coil or bottom fire, is apparent. The production of steam involves a considerable waste of heat, and in using it to evaporate liquids, its circulation through coils produces a large amount of condensed water at a temperature very nearly 100° C., the heat of which is generally lost. To evaporate by direct fire under the bottom of a pan is very inefficient and wasteful, and in the present case, in which no other metal but lead can be used for the pan, it requires great care and watchfulness to avoid melting the metal.

"For concentrating chemical solutions which are not affected by iron, as, for instance, copper sulphate, the new evaporator described in detail above can be constructed entirely of iron or steel and at much less cost. The pan itself, however, should always be placed in a wooden tank to prevent loss of heat by radiation.

"The outflowing concentrated solution passes into a 6-in. lead pipe and is conveyed to a collecting tank, which is covered to prevent the cooling of the liquor. At Argentine, one pipe serves to collect and convey the concentrated solution from 11 evaporators. From the solution tank the hot solution is drawn into a horizontal pressure tank, and is elevated by compressed air to a system of troughs placed above the crystallizing tanks. The troughs are

tightly covered with planks to avoid cooling, which would cause crystals to form in them. In construction the troughs are of California redwood, 10×11 in., in sections of 16 ft. The ends of the sections butt together and have an intervening rubber gasket. The sections are drawn together by iron flanges fastened to the sides of the trough a few inches from the end, iron bolts passing through both flanges. Brass screws are used in making the troughs, as iron nails or screws would not last. The joints between the bottom and the sides are coated with a fairly thick cement, which is made by boiling together waste rubber, resin, linseed oil, and ferric oxide. The cement when properly made should be quite liquid when very hot and stiff when cold, but never brittle or so hard that it cannot be kneaded between the fingers; nor should a piece of the stiff cement become liquid in water at a temperature of 80° to 90° C. The cement is elastic, and, as it never hardens, it keeps the joints well filled and overcomes the difficulty which arises from the shrinkage of one board from another. It has given very satisfactory results in the Argentine plant, and there has been absolutely no leakage in the troughs, which in aggregate length amount to nearly half a mile.

"The crystallizing department has 112 tanks, each of 720 cu. ft. capacity arranged in long rows intersected by several cross passages. Between each two rows is a track for transporting the blue vitriol crystals, on either side of which is a cement channel to receive and convey the mother liquor. The lead-lined wooden crystallizing tanks did not prove satisfactory, as the change in temperature caused by each filling with hot concentrated solution expanded the lead which did not subsequently contract in cooling; as a result in course of time the tank lining became wrinkled and broken and caused leakage and expensive repairs. The entire floor of the blue vitriol plant is made of cement

in order to collect any leakage that may take place. At present the tanks are made of concrete, and, though far superior to the original lead-lined wooden tanks, they do not come up to expectation because they also are affected by the sudden change in temperature when filled with the large bulk of hot concentrated solution. Although constructed with walls 20 in. thick, small cracks result, but leakage can be prevented by plastering a little cement on the outside of the tank. An experimental tank which has now been in use for several months seems to answer all requirements. It is built of bricks, having in the center of the walls a 2-in. space filled with a mixture of asphaltum and sand, which extends also from the sides under the bottom of the tank, thus practically forming a tank by itself imbedded in the brickwork. When heated by the sudden filling of the tank with hot solution, the asphaltum softens, and when gradually cooled it contracts without cracking.

"On the top of each tank are movable wooden frames supporting numerous strips of lead, on which the crystals form, as well as on the sides and on the bottom of the tank. The solution remains seven days in the tank. At the expiration of this time the mother liquor is drawn off and the crystals removed. Ordinarily 16 tanks are discharged daily, but during the hot summer months more time has to be given for the crystallization, and fewer tanks are discharged and refilled daily.

"The mother liquor is drawn off through a brass tube close to the bottom of the tank and flows in the above-mentioned cement channels in front of each row of tanks direct to the three pressure tanks placed in a pit. These tanks elevate the mother liquor to large storage tanks, where it is mixed with fresh copper sulphate solution from the dissolving and refining departments, and is ready to supply the evaporators. When the crystallizing tank is empty,

the movable frames with the lead strips and adhering crystals are lifted by a block and chain and the crystals knocked off with a wooden paddle. The crust of crystals from the sides is broken down. Rails are laid in recesses near the rim of the tanks so that the rails of the two opposite rows of tanks form a track for a hopper mounted on wheels. The crystals are shoveled with copper shovels into this hopper, which fills the push-car underneath through a spout with slide in the center. As the tanks are 6 ft. deep, the crystals have to be thrown at least 7 ft. high, and in doing this work some of the crystals unavoidably fall back into the tank, frequently striking the shoveler. It was found that this was very injurious to the men, especially in summer, when they are dressed scantily and perspire freely. Their bodies became covered with deep sores, which were very painful, although not dangerous, and the men naturally shunned the work and had to be replaced. Finally this branch of the plant was closed during the months of July and August.

"To overcome this very disturbing feature, I have constructed and set in successful operation the device illustrated in Fig. 15. On top of the hopper is mounted the frame *KK* with a turntable and circular track underneath which rests on a number of stationary wheels and is kept in place by the pin *P*. The object of this turntable is to make the apparatus available for opposite rows of tanks by rotation through 180°. The frame *K* is provided with a belt elevator *E* with copper cups, which can be brought into a horizontal position by means of the shaft *F*. On the same shaft are the pullies *L* and *M* which drive the elevator pulley *N*. The lower end of the elevator is provided with the boot *B*, which can be brought down to within a short distance from the bottom of the tank and into which the crystals are shoveled. The power is imparted by an electric motor on the platform of the frame, which receives the

electric current by an overhead wire with trolley extending along the rows of tanks. From the time this device was introduced the men were protected from the injurious effect

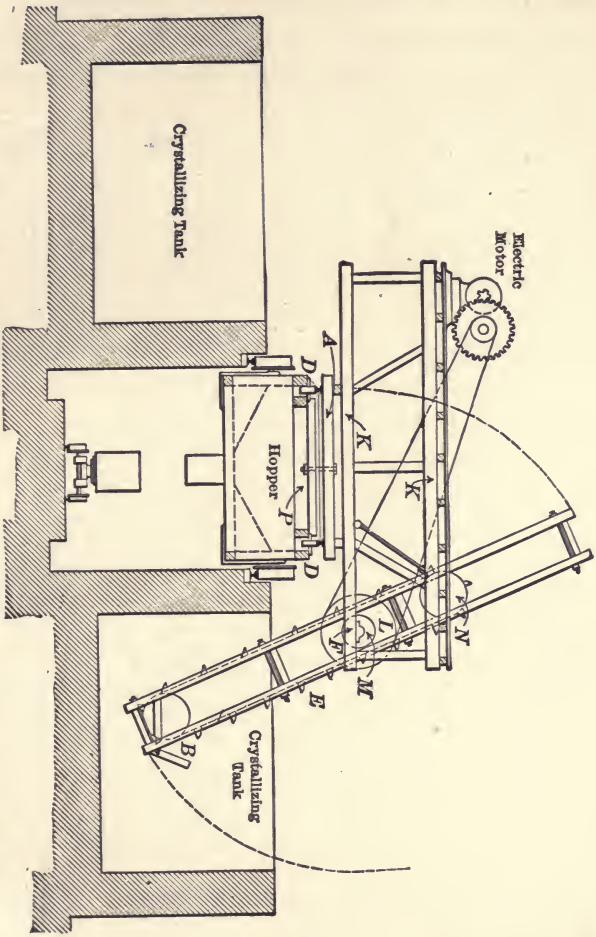


FIG. 15.—Device for Removing the Blue Vitriol Crystals from the Crystallizing Tanks.

of the blue vitriol crystals even during the hot summer months, as they had to shovel them only a short distance above the floor.

"The push-cars containing the crystals are wheeled to

the sizing and drying department and lifted by a platform elevator to the rim of a bin, into which the crystals are dumped. From this bin the crystals are fed between a fast-revolving roll and a plate provided with teeth, which breaks the crusts of crystals without injuring the individual crystals. After passing the rolls the crystals drop into a small hopper having a short worm conveyor of copper at the bottom, which feeds a belt elevator provided with copper cups. The elevated crystals drop into an inclined trough and are washed by a stream of mother liquor. They then drop into a hexagonal revolving screen having the shaft and arms of brass. The screen itself is of maple wood perforated with holes 0.375 in. in diameter. All crystals smaller than 0.375 in., together with the mother liquor, pass through a second inclined trough to another revolving screen, which is of sheet copper having 0.125-in. perforations. The mother liquor, with the very fine crystals, dirt, and sediment, after leaving the second screen is conveyed to an agitating tank and heated by a steam jet to dissolve the very fine crystals. The resultant solution is finally sent through a filter press, the clear liquor flowing to the storage tanks.

"By using mother liquor to wash and screen the crystals, the fine crystals are as clean and pure as those of larger size. At the present time the blue vitriol crystals are dried in 10 brass centrifugal machines and conveyed to the storage bins.

"The crystals, having been obtained from a neutral solution, are of a very deep-blue permanent color which is not affected by light except in the direct rays of the sun. They do not change into a bluish-white powder, which is the case with crystals made from an acid solution."

The American Smelting and Refining Co. is introducing the essential features of this method for the purification of foul electrolytic solutions at its Perth Amboy plant.

As the process requires the electrolyte to be first neutralized, and as this is done by adding to it cupric oxide (roasted copper matte), the bulk of solution obtained will increase. This increase may be worked off in two ways: 1, by treating the surplus solution in a separate system of tanks in which lead anodes and cathodes are used, copper being removed, while sulphuric acid is set free and is used to acidify that part of the refined and neutral electrolyte which goes back to the refinery; or, 2, by making blue vitriol, in which case, of course, sulphuric acid must be bought for addition to the refined neutral electrolyte. Special conditions in any given case determine which of these two methods should be preferred.

Treatment of Slimes.

(By Robert L. Whitehead.)

The slimes produced in the electrolytic refining of copper vary in precious metal content from 1500 to 22,000 oz. silver and from 4 to 200 oz. gold per ton, the copper contained being from 10% to 40%, in the form of metal, copper oxide, copper sulphide, and copper sulphate, the last-named combination being due to imperfect washing of the slimes.

The usual treatment of slimes in large smelting and refining works equipped with a desilverizing department is to add the dried slimes in paper bags of 10 or 15 lb. capacity to the charge of retort metal on the cupel hearth. The copper and impurities are oxidized and pass off in the slag, while the gold and silver is absorbed in the refined retort metal remaining on the cupel. The copper dross is treated in a shaft furnace for the recovery of the copper, antimony, and lead, the copper being regained as copper matte.

In electrolytic copper refineries the slimes are usually treated by the sulphuric acid method, which is modified

according to the character of the material. In ordinary practice the wet slimes from the tank-room are dried in a centrifugal dryer having 30-mesh phosphor bronze screens in place of the usual filter cloth. The coarse particles of copper are caught on the screen, while the slimes pass through into a storage tank. In this treatment about 10% by weight of the slimes is separated as metallic copper very rich in silver, which is added to the charge in the anode furnace. The slimes after settling are transferred to a large tank lined with 12-lb. lead and equipped with two steam coils extending its full length. Hot air is forced into the solution by an injector. Sulphuric acid in the proportion of 1500 lb. of acid (66° B.) per ton of slimes is then added and the solution boiled from 10 to 12 hours, which results in the dissolving of most of the copper, 66% of the arsenic and all of the bismuth and iron. The supply of steam is then shut off and the solution allowed to settle. The supernatant liquor very rich in impurities is siphoned into storage tanks and subsequently transferred to the evaporators for the manufacture of copper sulphate crystals (bluestone). The tank is then filled with water up to the level of the original sulphuric acid solution, the steam is turned on, and the temperature again raised to the boiling point. When this is done an addition is made of the settlings from the acid-parting kettles, which consist of anhydrous sulphate of copper and considerable silver sulphate, and the contents of the tank are thoroughly mixed. The copper precipitates metallic silver from the silver sulphate solution, being itself transformed to copper sulphate, and the treatment is continued until metallic silver is no longer produced. Should the silver sulphate be in excess of the corresponding quantity of copper needed to precipitate its silver content, a small addition of untreated slimes is made to supply the deficiency. The slimes are then washed several times by decantation, transferred to filters, and

washed with boiling-hot water. They are then transferred to cast-iron drying pans and dried in a furnace, the dried product being subsequently mixed with sand and soda ash and melted in a reverberatory furnace capable of holding 100,000 oz. of silver. The doré bars resulting from the furnace treatment assay from 950 to 960 fine in silver and from 10 to 20 in gold, the remainder being copper. The slag from the furnace melting contains 8% or 10% copper and 300 to 400 oz. silver per ton, the quantity produced depending upon the richness of the slimes. If the slimes are very rich the quantity of slag need not exceed 200 lb. per ton of slimes treated. The doré bars are placed in cast-iron kettles and parted by sulphuric acid (66° B.), similarly to the process in use at the New York Assay Office and at other government refineries, or they are parted electrolytically by the Moebius or the Thum-Balbach process.

The cement silver obtained in acid parting is thoroughly washed with hot water, placed in a hydraulic press and pressed into cakes of 1500 to 2000 oz. weight, which are removed from the press and charged without drying into a refining furnace of 100,000 oz. capacity. A small quantity of niter is thrown on the metal to remove the tellurium contained in the silver. When this is accomplished the molten refined silver is cast into 1200-oz. molds. The refined metal varies from 998 to 998.5 in fineness.

The gold is transferred to small parting kettles and boiled with sulphuric acid (66° B.) to dissolve the remaining silver. When this is accomplished a few lumps of saltpeter are added to the solution and the boiling continued for two or three hours to remove the small quantity of silver still contained in the gold and to coagulate the finely dissolved gold, which is of advantage in diminishing the quantity of float gold produced in the subsequent washing. The gold is then dried, melted under borax, and cast into bars of 993 to 996 fineness.

Generally, in electrolytic copper refineries, the copper sulphate solution formed by the reduction of the silver sulphates is added to the copper electrolyte in order to utilize the free sulphuric acid which is present to the extent of from 8% to 10%. The impure solution from the slimes tank is concentrated by evaporation to 42° B. and crystallized, the crystals formed being purified by repeated solution and crystallization until of marketable purity. The mother liquor from the crystals contains about 40% sulphuric acid, which is utilized by heating in a lead pan to 60° B. and subsequent cooling in iron pans. During the cooling, basic salts of iron and copper are separated. The resultant acid solution is used either in parting the doré bars or in the first treatment of the slimes. The slags produced in refining the slimes are treated in several ways: 1. By addition to the slags from the anode furnace, which, however, has the objection that the resultant copper is very impure and must be separately treated in the tank-room. 2. By treatment in a shaft furnace with litharge, which yields a copper matte and a silver-lead bullion. The latter is cupelled for silver, the litharge formed being used to treat another lot of slime slag. 3. By melting the slag with lead in a small reverberatory, as at the Raritan Copper Works. 4. By mixing with soda ash and melting in a reverberatory furnace, which yields a very clean slag and a very base bullion. This slag is sold to lead smelters, as it contains less than 60 oz. silver per ton and practically all of the antimony and tellurium of the original slimes. The base bullion is treated by adding small quantities to the regular charge of the softening furnace. The last-named method is the one used at the present time by the Seattle Smelting and Refining Co., at Seattle, Wash., in the treatment of the slimes produced by the Amalgamated Copper Co.'s plants at Great Falls and at Anaconda, Mont.

RÉSUMÉ OF MODERN PRACTICE IN ELECTROLYTIC WORKS.

1. *Anodes:* Precious metal bearing copper, refined to as high a percentage as is commercially practicable, say 96% to 99% Cu.

2. *Cathodes:* Thin sheets of electrolytic copper, deposited upon and stripped from greased lead or copper plates.

3. *Electrolyte:* Solutions containing not less than 12% and not over 20% bluestone ($CuSO_4 + 5H_2O$) and from 4% to 10% free sulphuric acid. It is very important that the constantly decreasing acidity and the constantly increasing copper contents of the electrolyte be maintained within these limits. A small quantity of salt or hydrochloric acid is always added to hinder any possible solution of silver and to prevent "sprouting" or brittleness of the cathodes. Ammonium sulphate is sometimes added when considerable arsenic is present.

4. *Temperature:* Heating the electrolyte up to between 40° and 50° C. is advantageous, because it decreases the electrical resistance of the solution and increases the tensile strength of the depositing copper. It is essential to maintain the temperature as *evenly* as possible at the point fixed upon, and to avoid appreciable differences in temperature between the upper and lower portions of the solution.

5. *Current Density:* From 4 to 45 amperes per square foot of cathode surface, according to the cheapness of power, the grade of the anodes in silver and impurities, and the purity of the electrolyte.

6. *Voltage:* 0.1 to 0.3 V., according to the current density, composition of the anodes and electrolyte, temperature, structure of the electrodes, and the distance the latter are placed apart.

7. *Products of Refining:*

(*a*) *Cathode copper* (99.86% to 99.94% Cu), the yield being from 97% to 99% of the copper contained in the anodes refined (barring the anode scrap), and 1% to 3% of the copper being recovered as bluestone.

(*b*) *Fine silver*,
(*c*) *Fine gold*,
(*d*) *Base bullion*, containing antimony, arsenic, and tellurium,
} obtained from the anode slimes.

(*e*) *Bluestone*,
(*f*) *Impure arsenical copper*,
(*g*) *Arsenious acid*,
} obtained both from the anode slimes and the electrolyte.

(*h*) *Nickel vitriol*, obtained from concentrated electrolytic solutions.

TABLES GIVING OUTPUTS AND OTHER DATA OF ELECTROLYTIC COPPER REFINERIES.

The subjoined carefully compiled statistical tables show that the world's average production of electrolytic copper is now about 883 short tons daily, of which 764 tons, or 86.5%, are supplied by the United States. Of the balance of the world's production of about 119 tons daily or approximately 13.5%, Great Britain produces a little over 8.8%, Germany about 2.75%, and France a little over 1.6%.

The United States now produces at the enormous rate of 278,860 tons of electrolytic copper, which at $260 per ton is worth $72,503,600, annually. The by-product recovered daily contains about 74,100 oz. silver and 948 oz. gold, which equals an annual output of over twenty-seven million ounces of silver, valued at nearly $13,000,000, and more than three hundred and forty-six thousand ounces of gold, valued at $7,152,233.

According to the Treasury Bureau of Statistics, the

ELECTROLYTIC COPPER REFINERIES IN THE UNITED STATES OPERATED IN 1903.

No.	Name of Company and Location of Works.	Kind of Material Chiefly Treated.	Approximate Daily Copper Output in Tons (2,000 lbs.).	Number and Capacity of Generators. Kw. = Kilowatts.	No. of Tanks in Refinery.	Arrangement of Electrodes.	Approximate Daily Output of Gold and Silver from Slimes.
1.....	Raritan Copper Works (United Metals Selling Co.), Perth Amboy, N.J.	Converter copper from Boston and Montana, Butte and Boston, United Verde, Cobar, Old Dominion, Arizona Copper, Copper King, Ltd., Highland Boy, Bingham & Green Consolidated Co.'s.	150 to 200 (Cap. 200)	Five @ 600 Kw.	1,600	Multiple.	8,000 to 10,000 oz. Ag. 175 to 200 oz. Au.
2....	Anaconda Mining Co., Anaconda, Mont.	Anaconda anodes.	84 (Cap. 150)	Five @ 270 Kw. Two @ 220 Kw.	1,200	Multiple.	9,000 oz. Ag. 40 oz. Au.
3....	Guggenheim Refinery (Perth Amboy Plant) of Amer. S. & R. Co., Perth Amboy, N. J.	Anodes and pig copper from Mexico, Utah, and Colorado.	100 (Cap. 150)	Three @ 520 Kw.	816	Multiple.	25,000 oz. Ag. 200 oz. Au.
4....	Nichols Chemical Co., Brooklyn, N. Y.	Converter copper from the Mountain Copper, United Copper, Copper Queen, and Granby Co.'s and metal from Canadian and Spanish pyrites cinders.	120	Six @ 75* Kw.	120	Series.	6,000 oz. Ag. 204 oz. Au.
5....	Baltimore Smelting & Rolling Co. (Baltimore Copper Works), Baltimore, Md.	Converter copper from Anaconda, Mt. Lyell, and part of the Germania Works output.	80 (Cap. 100)	Eleven @ 80 Kw.	540	L. p. series. S. p. multi.	6,400 oz. Ag. 28 oz. Au.
6....	Boston and Montana Cons. Copper and Silver Mining Co., Great Falls, Mont.	Boston and Montana anodes.	75	Two @ 810 Kw.	324	Multiple.	5,000 oz. Ag. 70 oz. Au.
7....	Balbach Smelting & Refining Co., Newark, N. J.	Orford anodes and miscellaneous.	45 (Cap. 50)	One @ 300 Kw. Two @ 125 Kw.	430	Multiple.	3,000 oz. Ag. 15 oz. Au.
8....	De Lamar Copper Refining Works, Cartaret, N. J.	Blister copper from Bully Hill mines, Cal., Tacoma Smelting and U. S. Mining Co.	50	One @ 520 Kw.	408	Multiple.	10,000 oz. Ag. 200 oz. Au.
9....	Buffalo Smelting Works, Black Rock, N. Y.	Lake Superior argentiferous native copper "mineral."	30	One @ 510 Kw. Two @ 48 Kw.	270 490	Multiple. Multiple.	600 oz. Ag. — oz. Au.
10....	Chicago Copper Refining Co., Blue Island, Ill.	By-products and miscellaneous pig copper.	5	Two @ 64 Kw.	250	Multiple.	100 oz. Ag. 3 oz. Au.

* Doubtful.

Country.	No.	Name of Company and Location of Works.	Kind of Material Chiefly Treated.	Approximate Daily Copper Output in Tons (2,000 lbs.).	Number and Capacity of Generators. Kw. = Kilowatts.	No. of Tanks in Refinery.	Arrangement of Electrodes.
Great Britian ...	1....	Bolton & Sons, Ltd., Frog-hall, Eng.	Gold and silver bearing "bottoms."	18 to 20 (Cap. 24)	Eight @ 75 Kw.	550	Multiple.
	2....	Pembrey Copper Works (Elliott's Metal Co.), Burry Port, South Wales.	Gold and silver bearing "bottoms."	18 to 20	385 Kw.	1,065	Multiple.
	3....	Bolton & Sons, Ltd., Widnes, England.	Gold and silver bearing "bottoms."	10 to 12	Four @ 75 Kw.	240	Multiple.
	4....	Leeds Copper Works, Hunslet, Leeds.	Chili bars (96% Cu).	10 to 12 (Capacity)	Four @ 170 Kw.	216	Elmore.
	5....	Vivian & Co., Swansea, Wales.	Gold and silver bearing "bottoms."	8 to 10	.....	.....	Multiple.
	6....	McKechnie Bros., Widnes, England.	Miscellaneous crude copper.	9*	Three* @ 75 Kw.	234*	Multiple.
Germany.....	1....	Norddeutsche Affinerie, Hamburg, Germany.	Miscellaneous crude copper.	10	Ten @ 8* Kw.	600	Multiple.
	2....	Mansfeld Kupferschiefer-bauende Gewerkschaft, Eisleben.	Gold and silver bearing "bottoms."	5	.....	.....	Multiple.
	3....	Communion Huettenwerk, Oker.	.....	5	Sixteen @ 4* Kw.	600*	Multiple.
	4....	Borchers Bros., Goslar.	.....	1	.....	.....	Multiple.
	5....	Elmore Metall Actiengesellschaft Schladern an der Sieg.	Chili bars.	1*	.....	.....	Elmore.
	6....	Stadtberger Hütte, Niedermarsberg.	Argentiferous cement copper.	0.9 to 1.0	.....	.....	Multiple.
	7....	Altenau Kupferhuette, Altenau, Harz.	.....	0.8 to 1.0	One @ 21 Kw.	.....	Multiple.
	8....	C. Schreiber, Burbach, Siegen.	.....	0.2	One @ 11 Kw.	.....	Multiple.
	9....	Allg. Elektro-Metallurgische Gesellschaft, Papenburg, a. d. Ems.	Ni + Cu matte.	0.2*	.....	.....	Hoepfner.
Austria-Hungary..	1....	Bergbau u. Eisenhuettengewerkschaft, Witkowitz, Moravia.	Pyrites cinders from Acid Works.	0.25 to 0.30	One @ 3 Kw. One @ 5 Kw.	72	Multiple.
	2....	K. K. Berg u. Huettenverwaltung, Brixlegg, Tyrol.	Black copper (90% Cu).	0.12 to 0.14	Two @ 5 Kw.	60	Multiple.
France.....	1....	Société d'Electro-Metallurgie, Dives.	Chili bars.	10 to 12*	Four @ 170 Kw.	216	Elmore.
	2....	Société Anonyme des Fonderies et Laminoirs, Biache St. Vaast.	.....	2*	Five @ 6 Kw.	100*	Multiple.
	3....	Grammont Affinerie, Pont de Cheruy.	.....	1.1*	.....	.....	Multiple.
	4....	Hilarion, Roux et Cie, Marseilles.	.....	0.28	One @ 3 Kw.	40	Multiple.
Russia	1....	Kalakent Copper Works (Von Siemens & Heirs), Kalakent, Caucasus.	Blister copper.	1.2 to 1.4	Two @ 24 Kw.	102	Multiple.
	2....	Nikolajev Works, Nijni Novgorod.	.....	0.75	.....	70	Multiple.

* Doubtful.

copper exports of the United States, chiefly consisting in electrolytic copper, for the year 1902, alone represented a value of $45,485,598, as against $33,534,899 in 1901, and were only exceeded in value by the country's exports of manufactures of iron and steel and of mineral oils.

There are now in active operation, or ready to be placed in commission, 33 electrolytic copper refineries in the world, not including the plant of the Osaka Electrolytic Refining Co., now being constructed at Osaka, Japan.

CHAPTER II.

DESCRIPTION AND VIEWS OF ELECTROLYTIC COPPER REFINING WORKS.

THE present practice and appliances used in electrolytic copper works are described in detail in the following pages, and the characteristic arrangements of plant and the equipment are illustrated, wherever it has been possible to obtain views, in order to give the reader a fair and comprehensive conception of the present status and magnitude of electrolytic copper refining.

The works are grouped under the heads of the countries in which they are situated, starting with the United States and followed in order by Great Britain, Germany, Austro-Hungary, France, and Russia, and under each head the refineries are considered in the order of their relative capacities.

Not including the plant of the Osaka Electrolytic Refining Co., in Japan, which is reported to be under construction, they embrace a total of 33 refineries.

A. UNITED STATES.

1. The Raritan Copper Works.*

BY LAWRENCE ADDICKS.

The Raritan Copper Works, in its location at Perth Amboy, N. J., possesses unusual advantages for the econom-

* Taken from *The Mineral Industry*, vol. ix, by kind permission of the author and publishers.

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ical refining of copper. The transportation facilities are such that the most favorable freight rates, both domestic and foreign, are obtainable and the proximity of New York allows the lowest prices on supplies to be procured. Spurs from the Pennsylvania Railroad, the Central Railroad of New Jersey, and the Lehigh Valley Railroad run directly into the yards of the works, and a private line of lighters is maintained from the company wharf, a short distance from the furnace building, to New York by way of Staten Island Sound. The lighters afford a cheap means of placing the refined product alongside outward-bound vessels at New York and the competition among the different railways precludes the possibility of the company ever being placed at the mercy of a single line. There is sufficient depth of water at the wharf to allow large vessels to load and unload directly at the works should it be found desirable.

The plant was designed for a maximum monthly production of from 10,000,000 to 12,000,000 lb. of cathode copper in the tank-house and from 15,000,000 to 18,000,000 lb. of refined copper from the furnaces. The output of precious metals varies with the character of material treated, but may be stated as 300,000 oz. of silver and 5000 oz. of gold per month. A very wide range of raw material is treated, about the only requirement being that the copper content shall be equal to that of good blister copper. The excess of furnace capacity over tank-house capacity makes it possible to treat a considerable quantity of outside cathodes. Anodes from outside sources also are more or less handled.

General Plan.—The general arrangement of the buildings and railroad connections is shown on the accompanying ground plan (Fig. 16), which is self-explanatory. The standard-gauge tracks connecting with the several railway systems are indicated by heavy lines, while the narrow-gauge tracks of the industrial railroad, as it is called, are

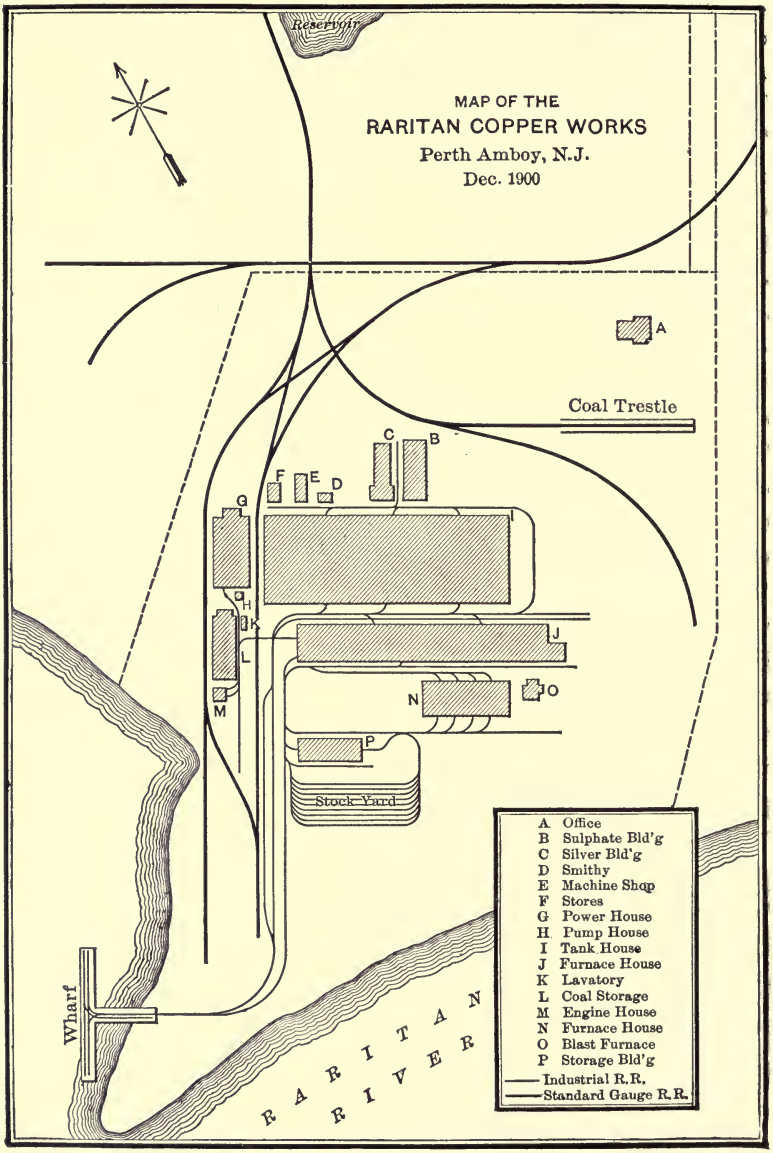
Reservoir
MAP OF THE
RARITAN COPPER WORKS
Perth Amboy, N.J.
Dec. 1900
A
Coal Trestle
C
B
F
E
D
G
I
H
K
J
L
M
N
O
P
Stock Yard
Wharf
RARITAN RIVER
A Office
B Sulphate Bld'g
C Silver Bld'g
D Smithy
E Machine Shop
F Stores
G Power House
H Pump House
I Tank House
J Furnace House
K Lavatory
L Coal Storage
M Engine House
N Furnace House
O Blast Furnace
P Storage Bld'g
Industrial R.R.
Standard Gauge R.R.

FIG. 16.

distinguished by light lines. This railroad is equipped with two locomotives and a large number of iron flat cars of a capacity of 10 tons each, and it binds all the buildings together with a network of tracks. All incoming copper bullion is unloaded from the freight cars directly on these small ones and taken to the storage building, where it is weighed, without being removed, in drafts of about 15,000 lb. Ample yard tracks are provided, so that such material as is not for immediate use may be temporarily stored on the cars, thus avoiding subsequent rehandling

The greatest care is used to obtain accurate weights. Two scales are provided and all material is weighed twice. Furthermore there are two weigh-masters who keep independent records, while a third man checks the number of pieces. The scales were installed by the Fairbanks Co., and their representative makes weekly visits to the works to examine and adjust them. For further reassurance that they are in perfect adjustment a car loaded with standard weights is run on several times a day. Heavy sampling drills and a coffee-mill are also provided in the storage building.

The works proper, shown by the dotted fence line on the map, cover about 45 acres. The various buildings are grouped about the tank-house as a center and all are so arranged that future extensions may be made with the least possible expense and inconvenience. A coal-storage building is conveniently placed near the power-house, and a coal trestle to supply the furnaces is located at the opposite side of the grounds.

The general use of steel construction throughout the plant, the thorough fire protection, and the universal application of labor-saving machinery are noteworthy features. The three furnace buildings are entirely of metal and need no special fire protection. The tank-house has a steel skeleton with brick curtain walls and is protected by a

thorough system of automatic sprinklers and eight inside hose connections. The other main buildings are protected by sprinklers. The coal-storage building is provided with a number of thermostats buried in the coal heaps. For fire service an Underwriter pump of a capacity of 1000 gal. per minute is kept in constant readiness to be thrown on full head at an instant's notice. The water supply consists of an 8-in. city main, a 24-in. line from the river, two wells, and a reservoir. In an emergency a portion of the regular pumping system may also be pressed into fire service. A number of fully equipped hose houses and a thoroughly organized fire department complete the protective measures.

In passing it may be of interest to state that the ground was broken for the erection of the first building on August 1, 1898, and the current was turned on in the tank-house March 23, 1899, an interval of less than eight months.

Office Building.—The office building is two and one-half stories high and about 75×90 ft. Here are located the general offices, the drafting-room, and the chemical and physical laboratories. The chemical laboratory is divided into three rooms, the assay-room, the balance-room, and the general laboratory. The assay-room is equipped with three gas muffle furnaces, a gas crucible furnace, a rolling machine, a cupel machine, pulp balance, bucking-board, etc. The balance-room contains a set of five gold, analytical, and pulp balances, supported on a special foundation to avoid vibration. The general laboratory, which is about 20×35 ft., is furnished with the customary gas, water, electricity, suction, hoods, etc. A unique feature is the use of electric heaters as hot plates in the hoods. On the opposite page is tabulated the routine work of the laboratory.

There are also special determinations occasionally made, as analyses of coal, water, etc., and the copper, arsenic,

and antimony contents in wire bars in the event of a low conductivity report by the physical laboratory, but these are of comparatively infrequent occurrence. For details of the methods of analysis employed, the reader is referred to the article on copper analysis by Titus Ulke,* the methods there described agreeing closely with those employed here.

Frequency.	Material.	Determinations.
Twice daily	Blast-furnace slag	Cu.
Daily	Electrolyte (*a*)	Cu, Acid, Sp. Gr.
	Copper bullion	Cu, Ag, Au.
	Anodes	Cu, Ag, Au.
	Blast-furnace pigs	Cu, Ag, Au.
Weekly	Cathodes	Cu, Ag, As, Sb.
	Electrolyte	Cu, As, Sb, Cl.
	Slimes	Cu, Ag, Au.
	Silver slabs	Ag, Au.
	Silver slag	Cu, Ag, Au, Pb
	Fine silver	Ag.
	Fine gold	Au.
Occasionally	Blister slag	Cu, Ag, Au.
	Refinery slag	Cu.
	Blast-furnace charge	Cu, Ag, Au, SiO_2, Fe, CaO.
	Cement copper	Cu, Ag, Au.

(*a*) Performed at laboratory in tank-house, but included here for the sake of completeness.

The physical laboratory is equipped with a Queen conductivity bridge, a 6000-lb. Riehlé tensile machine, and a 500-lb. Riehlé torsional wire-testing machine. Daily tests are made of the conductivity of each lot of copper produced by the refining furnaces, whether ingots, wire bars, or cakes. The bridge is checked each day against a standard. No. 12 B. & S. annealed wire is used for these conductivity tests; it is drawn in the shops from small sample bars taken from each charge. The written approval of the physical laboratory is required before any lot is allowed to leave the works.

* *Engineering and Mining Journal*, Dec. 16, 1899.

Power-house.—The power-house is of modern design, built of brick and steel. It is divided by a central longitudinal brick partition into boiler- and engine-rooms. The general arrangement is clearly shown in the sectional drawing (Fig. 17). The building is thoroughly fireproof, and in this connection it may be noted that the engine-room floor is constructed on the Ransome system of cement

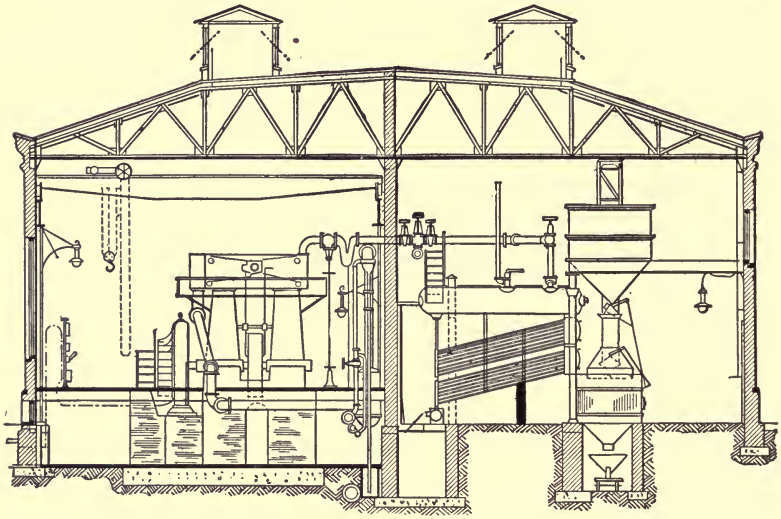

FIG. 17.—Cross-section of Power-house.

throughout. A basement 9 ft. in the clear is provided beneath the engine-room.

The boiler-room contains the boiler equipment only, consisting of eight 400-H.P. and two 200-H.P. Babcock & Wilcox water-tube boilers. These are set in pairs, with a passageway between each battery for the convenient blowing of tubes and cleaning of dust-chambers. The furnaces are of the Murphy automatic-stoking type. Directly beneath them is an ash-tunnel running the length of the building; through this tracks are laid for a side-dumping

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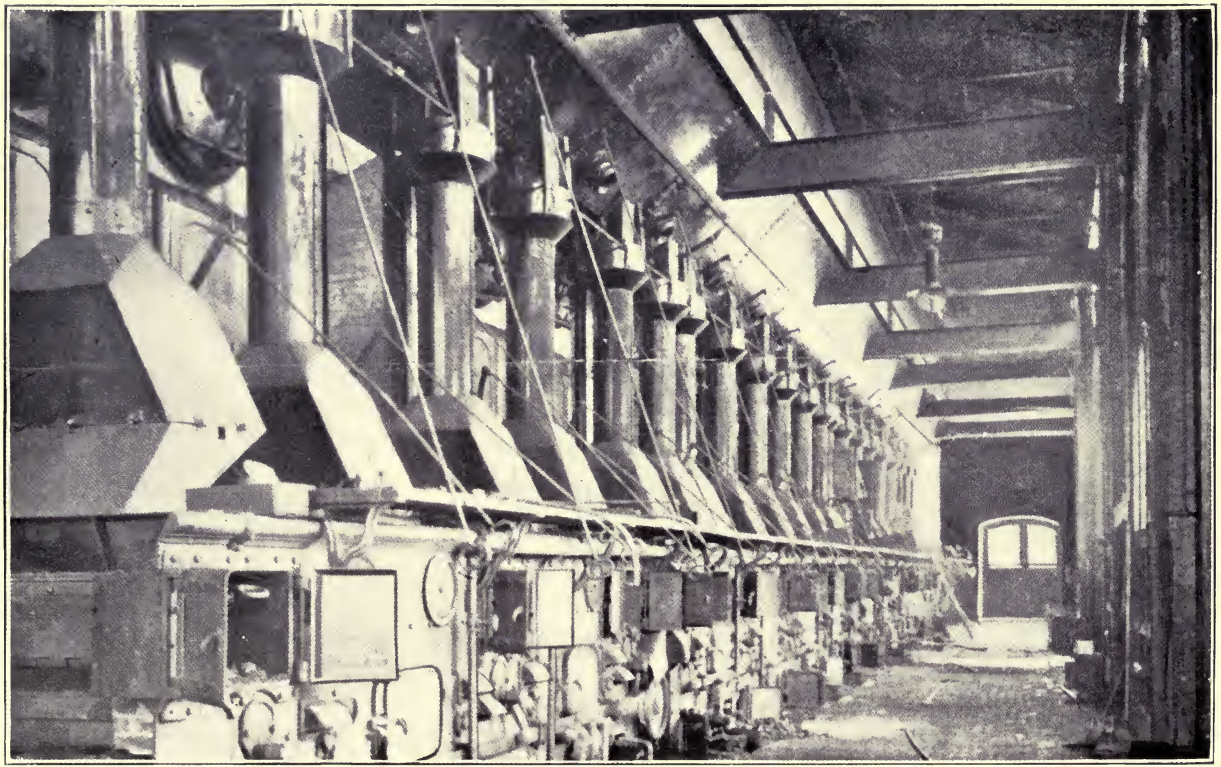

FIG. 18.—Boiler-room of the Power-house, showing the Automatic-stoking Furnaces.

[*To face page* 63.]

steel car. Under each furnace is a steel hopper the dimensions of which correspond to the capacity of the car, furnished with a sliding gate at the bottom. When the car is placed in position, this gate is opened, the ashes are dumped, and the car is pushed through the tunnel to a hydraulic lift at the south end of the building, raised to grade and run out to the lowlands for dumping. Over the furnaces is a coal hopper of 393 tons capacity, extending the length of the boiler-room, with a discharge nozzle over each feeding magazine. At the end of each nozzle is a swinging gate with lever and rod connection extending down to the front of the furnaces within easy reach of the firemen. Directly beneath each nozzle is hung a heavy sheet-iron chute of 13 cu. ft. capacity, at the lower end of which is another swinging gate controlled with lever and rod as before. These chutes and levers are shown in the photograph of the boiler-room (Fig. 18). There are two furnaces to each boiler and one double and two single magazines to each pair of furnaces. The upper gate levers are connected to a counter in such a manner that the number of chutes of coal used for each boiler is registered, thus allowing the coal consumption readily to be computed.

The coal is handled mechanically throughout its entire course, being dumped from the cars in which it is shipped into a hopper, then taken by a drag conveyor, screened, the coarse lumps crushed, recombined with the screenings, and elevated to the tower of the coal-storage building just south of the power-house. From this tower it may be conveyed either to the bins of the coal-storage building or directly to the hopper in the boiler-room. The space beneath each boiler where the grates and ash-pits are usually placed is used entirely as a combustion-chamber and for the collection of the heavier ash and soot which is carried through from the furnaces. The smoke-flue is built as a tunnel parallel with the ash-tunnel, and leads to a brick

stack 175 ft. high, at the south end of the building. There are individual dampers arranged for hand control and a main damper governed by a Spencer damper-regulator. The north boilers are used for electrolytic service, while the three south boilers are used independently for supplying steam for solution heating in the tank-house and for operating the general service-pumps and the light and power engines. These latter boilers are operated at 125-lb. and the former at 170-lb. gauge pressure.

The illustration of the power-house (Fig. 17) and the photograph (Fig. 19) show the general arrangement of the main piping. The steam-header is shown in section near the division wall. The valves allow a boiler to feed its own engine directly or to supply the main header in parallel with the other boilers as occasion may demand. With this system it is possible to repair the entire steam-header without interruption of the service or in turn to repair any one of the steam mains without discontinuing the service for more than one unit. A separator is inserted between the header and each throttle-valve. The engines for the electrolytic service, five in number, are vertical, cross-compound, and condensing, running at 150 revolutions per minute, each direct connected to its generator. The different generators vary slightly in capacity, but the largest, built by the General Electric Co., deliver 4500 amperes at an efficiency of 93.5%. The engines for supplying light and general power are horizontal, tandem-compound, running at 265 revolutions per minute, with generators direct connected. All of the engines were built by the Ball & Wood Co. Efficiency tests of the vertical Corliss engines showed an economy of from 13.4 to 13.7 lb. of steam per I.H.P. per hour. The exhaust piping of the engines leads from the gallery down past the generators, through the floor to Berryman feed-water heaters and thence to Bulkley ejector condensers. Each engine has its independent in-

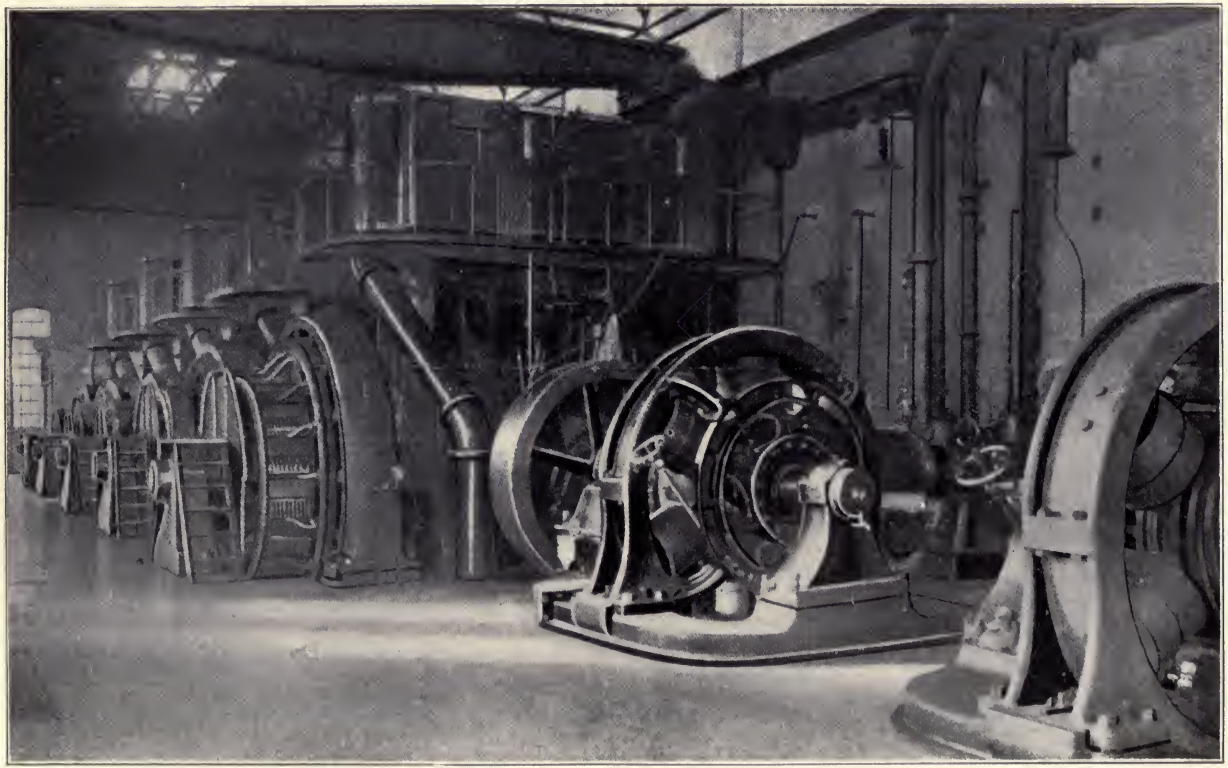

FIG. 19.—Power-house.

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termediate heater and condenser. The boiler feed-water passes from the city main through a meter in the north end of the power-house basement into a main running the full length of the building and tapped at each of the Berryman heaters. A parallel main receives the discharge from the heaters and carries it to a Cochrane open heater set directly above the feed-pumps at the south end of the building. The exhausts from the light and power engines and boiler-feed and general service pumps are taken into this heater. The Berryman heaters deliver the feed-water at 123° F. and the Cochrane heater raises this temperature to about 210° F. The feed-water is carried into the feeding main by duplex, tandem-compound Snow pumps. The branch for each boiler is provided with a Worthington hot-water meter and a specially graduated throttling-valve. Suitable thermometer wells and boiler oil injectors are placed in each boiler feed-pipe within easy reach and control of the engineer; the feed-pipes do not pass through the division wall into the boiler-room until after leaving the hot-water meters. A valve in the feed-line is also placed in the engine-room so that the engineer may control the supply of water if he so desires. Water-column, gauge-cocks, and steam-gauge for each boiler are placed along the division wall on the engine-room side, the piping leading directly through the wall to the drums of the boilers. There are also draft and pyrometer tubes in this wall at the rear of each boiler. In this way the engineer has the boiler performance entirely under his observation and control without going into the boiler-room.

At the extreme south end of the power-house is the pumping plant. It consists of two centrifugal pumps which take water for condensing purposes from a well fed by the river, two 24-in. stroke 3,000,000-gal. compound duplex pumps which are used expressly for supplying bosh water to the copper furnaces on a return system, including

the reservoir, a 350,000-gal. compound duplex pump used for supplying water for general purposes about the works, and the simple duplex Underwriter pump before mentioned, which ordinarily supplies a number of hydraulic lifts. Two Westinghouse 9.5-in. air-pumps supply air at 70 lb. pressure for cleaning generators, handling oil, acid, etc., and for operating pneumatic hoists.

The oiling system for the entire plant is a modification of the usual gravity system. A reservoir is placed at one end of the engine-room directly beneath the roof and is connected by suitable piping with the sight-feed and controlling valves which distribute oil to the various bearings. All of the valve-motion mechanism is lubricated with grease from compression cups. The engines are specially fitted with oil-ways, collecting-rings, and guards, and the waste oil is carefully caught and piped to a fire-proof oil-room in the basement In this oil-room there are two sets of filters and a receiving-tank from which the overhead tank is periodically filled. Compressed air is used for refilling the overhead gravity tank and a counter attached to a float registers the number of tanks of oil used. The valves and pistons of the engines are lubricated by means of Sterling, Jr., pumps There is a pump connected with each admission valve, operated by the exhaust-valve mechanism in such a manner that a minute quantity of oil is injected into the steam just prior to its admission to the cylinder at each stroke.

Tank-house.—The electrolytic plant is in a single building approximately 200×600 ft. The use of a steel skeleton, carrying the loads, and brick curtain walls, and the 7 to 8 ft. of head room in the basement are noteworthy features in the construction. The type of building is shown in the illustration (Fig. 20) and the photograph (Fig. 21). Thorough lighting and ventilation are supplied by an immense number of windows, a large high monitor, and a series of

FIG. 21.—View of Tank-house, showing the Arrangement of the Tanks and Electrodes and Overhead Cranes.

[*To face page* 66.]

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ventilating skylights. The main floor is made very heavy and can support a loaded train in connection with the industrial railroad. The basement is floored with a 6-in. layer

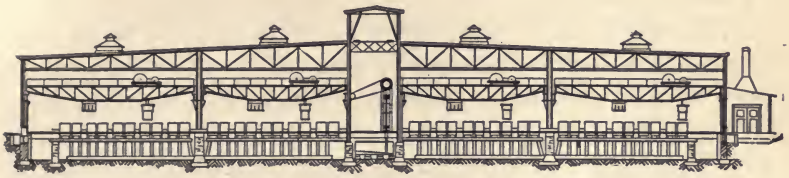
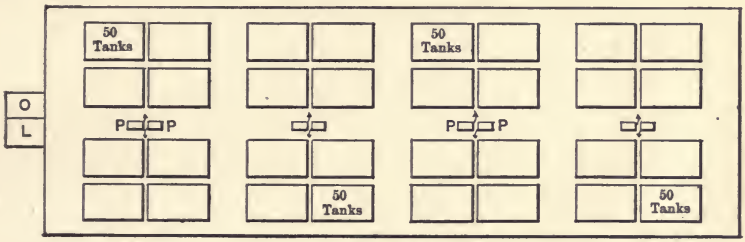


FIG. 20.—Cross-section of Tank-house.

of tar concrete which has proved very satisfactory in withstanding acid and trucking. There is a 5-ply tar and gravel roof, the planking of which is carried on steel trusses. The general ground plan is shown diagrammatically in Fig. 22.



GROUND PLAN

O, OFFICE. L, LABORATORY. P,P, PUMPS. TOTAL NUMBER OF TANKS, 1,600.

FIG. 22.—Tank-house.

An office and laboratory are provided at one end while the main-floor space is given up to the 1600 depositing tanks. The liberating tanks, 32 in all, are in small additions built on the north side. Emery-wheels, punches, and shears are placed along the end walls, and the solution pumps are situated in the main longitudinal aisle. Tunnels are provided from the basement to the power-house and silver buildings. Four electric cranes equipped with a special appliance for handling electrodes run the length of the building, each commanding 400 tanks. For convenience

in description the tank-house may be considered, first, from the point of mechanical operation, second, from that of electrical supply, and third, from that of distribution of electrolyte.

Operation.—The regulation multiple system is in use, the tanks being electrically in series and the electrodes in each tank in parallel. This necessitates the apportionment of a certain number of tanks as cathode-forming or "stripping" tanks. These, 180 in all, are divided between the two end sections, giving ready access to the special machinery along the end walls. The cathodes in these tanks are rolled plates of pure copper, 0.156 in. thick, the surfaces of which have been smeared with tallow which is kept fluid in steam-jacketed pots. These are used as a basis on which to form the thin cathode sheets for use in the regular depositing tanks. The edges are protected from deposition by grooved wooden strips* which are slipped on before the plates are put in position. After remaining in the stripping tanks 36 hours, they are removed, the wooden edges knocked off, and the thin sheet of deposited copper peeled from each side of the plate, the presence of the tallow having prevented any firm adhesion of the surfaces. The entire work of removing, stripping, and replacing a plate occupies but a few moments. The thin cathode sheets are taken to the shearing and punching machines, where two thin copper loops are riveted on. They are then flattened carefully out by beating with wooden paddles and hung in the depositing tanks from copper rods which are flattened at one end to prevent rolling. At the end of seven days the cathodes are removed, a tankful at a time, by the crane and dumped on the floor in one of the main cross aisles. The rods are taken out and the cathodes piled on

* These are no longer in use, as their purpose is better served by perforating or grooving the plates near their lateral and bottom edges and filling these perforations or grooves with a suitable insulating material.—TITUS ULKE.

cars of the industrial railroad to be taken to the furnaces. The shape and method of support of the electrodes may be seen in the drawing illustrating the details of tank construction (Fig. 23). The anodes are brought into the tank-

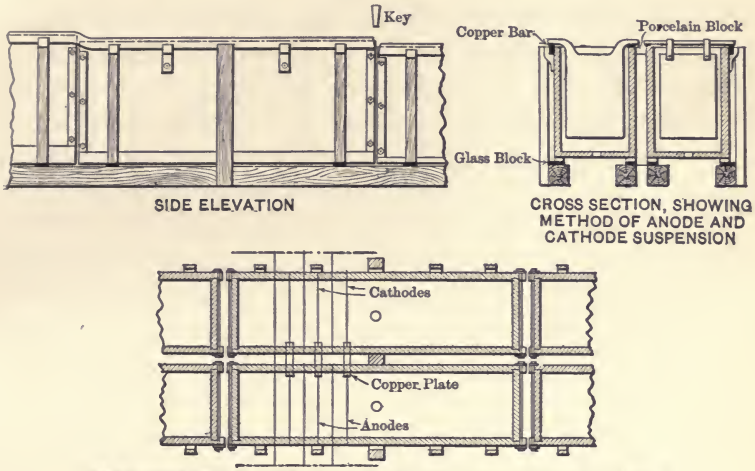


FIG. 23.—Details of Tank Construction

house on cars and hung in frames made of structural iron, which are designed to place the anodes in the same relative position that they are to occupy in a tank. When a sufficient number to fill one tank have thus been hung, the traveling crane picks them up without touching the frame and carries them to the tank in question, lowering them directly into place without any intermediate handling by the men. The crane is shown in action in the photograph of the tank-house (Fig. 21). Each anode weighs about 400 lb., and as there are 22 to a tank, the load weighs between 4 and 5 tons. In addition to the cranes, runways are provided over each separate row of tanks, along which trolleys travel that carry differential blocks for the convenient handling of single electrodes. These find constant

use in connection with the stripping tanks. The anodes remain in the tanks 43 days on an average, when they are taken out, scrubbed, and sent back to the anode furnaces as scrap. By careful reworking in the tanks all anodes the condition of which, on removal, warrants the labor of rehandling, the percentage of this scrap returned to the furnaces is kept down to about 9%. The slimes are removed but once in three months. Then the tanks are emptied of solution one at a time by means of steam siphons. The slimes are sluiced through an outlet in the tank bottom into barrels mounted on trucks in the cellar below.

Electrical Supply.—Electrically the tank-house is divided into units of 400 depositing and 8 liberating tanks each. These 408 tanks are all connected in series and form the load of one of the large generators in the power-house. There are 22 anodes and 23 cathodes in multiple in each tank. The arrangement of tanks in pairs with cross connections, as shown in the diagram of electrical connections (Fig. 23), combines convenience in handling with economical use of copper in conductors and minimum impairment of efficiency in event of short circuit occurring between a pair of electrodes. The main conductors are 1.25×4 in. bar copper, carrying about 4000 amperes. The connections between paired tanks are made by means of strips of copper. All contact resistances are kept as low as possible by the liberal use of emery. This gives a current density of 15 amperes per square foot of cathode surface, the end electrodes being credited with but one active side each. During cleaning, a tank is short circuited by use of the wedge or key shown in the drawing (Fig. 23). The conductors are supported by five clamps on each tank, three of which are carried down to the stringers below. The tanks are insulated from the building with the greatest care, glass blocks being used under all supports, and the main floor having a clearance of several inches. Bulging at the sides

is prevented by the alleyway floors and iron braces on the outside tanks.

Distribution of Electrolyte.—Each of the electrical units mentioned above is divided into two circulations, each consisting of 200 depositing tanks, four liberating tanks, a solution well, and a pump. Thus there are in all eight entirely independent circulations. The ground plan of the tank-house (Fig. 22) shows the way in which these units are placed in the building, each pump supplying four of the 50-tank squares as indicated by the arrows. These units are terraced in each direction as shown in the diagram (Fig. 24). The solution is carried from the supply-box

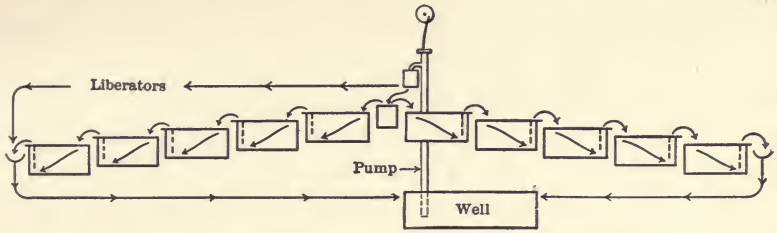


FIG. 24.—System of Circulation of Electrolyte.

at the pump along a main and supplies the tiers in multiple, so that each ounce of solution does duty in five tanks in series before being returned to the solution well to be pumped up again. The rate of circulation is controlled by the throw of the pump, which is of the plunger type; at the rate maintained, all the solution in a tank is replaced about every hour and three-quarters. The distribution is governed by valves at the crest of each tier. The spouts from tank to tank take the solution from the bottom of one tank and deposit it on the top layer of the next, thus maintaining a uniform density. The tanks are lined throughout with 8-lb. lead, the launders with 6-lb., and the solution well with 14-lb. A certain portion of the solution is taken from the supply-box at the pump through a small pipe leading

to the liberating tanks and thence returned to the well. These liberating tanks serve to regulate the copper content of the electrolyte. They are identical with the depositing tanks in construction and operation except that lead anodes are used. Their location, in small additions to the main building with special ventilators, prevents the excessive contamination of the tank-house atmosphere due to the fumes here given off. The solution is maintained at a mean temperature of 120° F. by steam coils in the wells. On those circulations which include stripping tanks the solution is cleansed of tallow by being forced under an inverted dam. The tallow is removed from time to time at the entrance side of the dam where it collects. A circulation may use the same solution a number of months before it becomes sufficiently foul to give any trouble; when this finally occurs a portion is run off into a storage well in the cellar and replaced by fresh solution. When a sufficient quantity of foul solution has accumulated in this well it is run over to the sulphate building; its subsequent treatment is described later in this article. The following partial analyses of a working solution and the copper deposited from the corresponding bath are taken from a regular assay report of recent date:

	Cu. %	As. %	Sb. %	Ag. Oz. per Ton.	Free H_2SO_4. %	$CuSO_4$ $5H_2O$. %	Sp. Gr.	Mean Temp.
Electrolyte .	4.25	1.1601	0.0295	.....	9.12	16.79	1.220	117° F.
Cathode. . . .	99.94	0.0013	0.0015	0.30				

Solutions more impure than this are constantly in use.

When slimes are to be removed, the tanks in question are cut out of service, the circulation being stopped by closing the valves on the individual supply pipes at the crest of the cascade, and the current being shut off by short circuiting. The traveling crane then removes the anodes,

a tankful at a time, and similarly the cathodes. The solution in the lowest pair of tanks is then emptied into the launder through a steam siphon. The plug in the bottom of the tanks being pulled out, the slimes are sluiced out with the residual few inches of solution into the slime barrels in the cellar below. The plug is replaced and the solution in the next pair of tanks siphoned into the pair just cleaned and the new electrodes placed in position by the crane, and so on. The circulation is stopped in 10 tanks at a time while cleaning, the current, however, being shut off from but four at a time. The slime buggies are pushed through the tunnel into the basement of the silver building, and their treatment will be described further along in this article.

Furnace Buildings.—There are three furnace buildings shown on the ground plan (Fig. 16) at *J*, *N*, and *O*. The first is about 80×600 ft. and contains four 50-ton anode furnaces and five refining furnaces of the same capacity. The second building is 80 × 200 ft. and contains four 25-ton refining furnaces. The third building is the blast-furnace building, which will be considered under a separate heading. These buildings have steel skeletons, corrugated-iron sides and roof, and checkered cast-iron floor-plates. The nine 50-ton furnaces are equipped with mechanical conveyors for the rapid casting of anodes in the case of four furnaces and wire bars in the case of the others. One 25-ton furnace is furnished with a special conveyor for casting cakes. The three others are used for making ingots and molds by hand ladling and one of them has a pit for making shot copper. A section of the large furnace building is shown in Fig. 25 and plan and sections of a 50-ton furnace are shown in Fig. 26. The charging side of the building being next to the tank-house allows a ready handling of cathodes to the refining furnaces. The tracks of the industrial railroad run the length of the building on both

sides. On the pouring side there is a traveling crane and a number of small jib cranes. At one end of the building is a ladle-drying furnace where the clay linings of ladles are quickly and cheaply baked.

The refining process presents nothing worthy of special note, the customary rabbling and poling being followed.

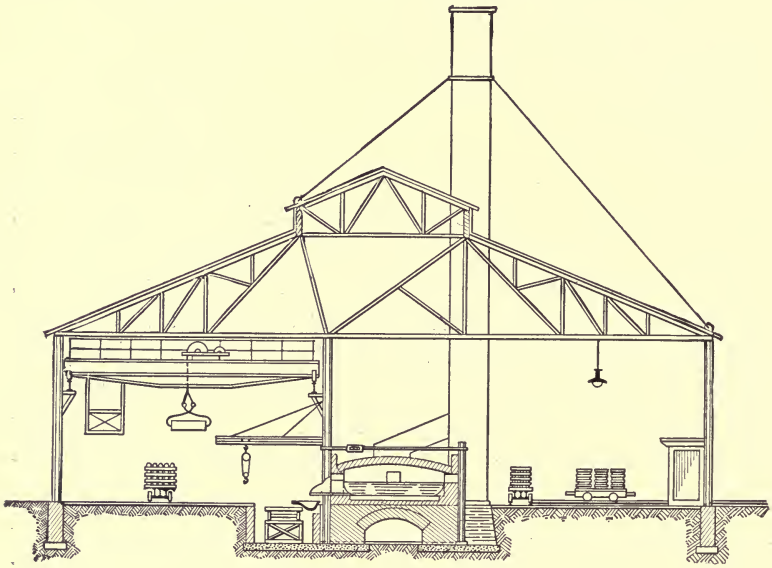


FIG. 25.—Section through Furnace Building.

The blister or anode furnaces pour a daily charge of up to 150,000 lb. each, which has been mixed to produce anodes containing from 100 to 120 oz. of silver per ton. The daily output of the wire-bar furnaces reaches 120,000 lb. each.

The mechanical conveyor of one of the wire-bar furnaces is shown in the photograph (Fig. 27). The molten copper is received in a ladle placed directly below the tap-hole launder, and is thence delivered to molds brought successively into position by a table conveyor. The ladle is of sufficient size to hold the copper which flows from the spout

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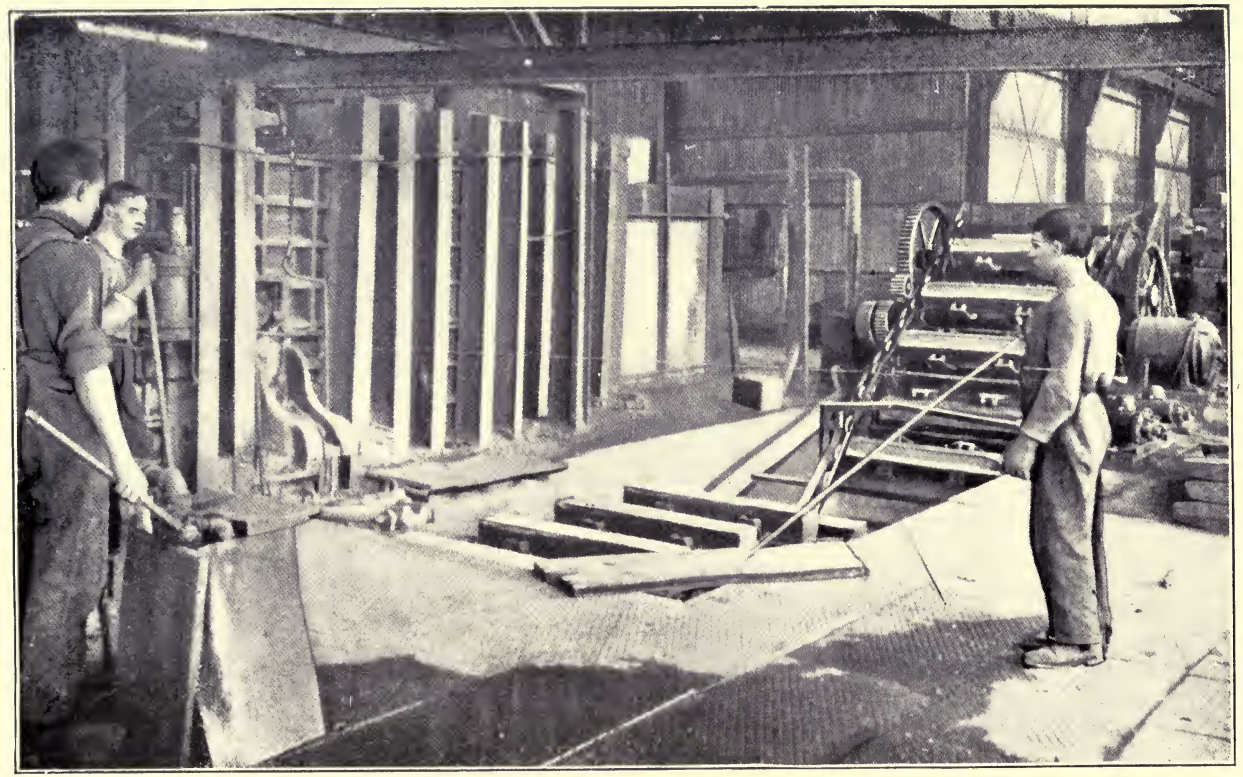

FIG. 27.—Mechanical Casting Apparatus for Casting Wire Bars.

[*To face page* 75.]

while the conveyor is in motion. The stream from the furnace is governed by bits of wood thrust into the spout. The ladle, which is of iron, clay-lined, is raised and lowered by a hydraulic piston controlled by the ladler. The copper in the ladle is protected from oxidizing influences by a layer of charcoal. The conveyor consists essentially of a series of copper molds carried by an endless chain of link

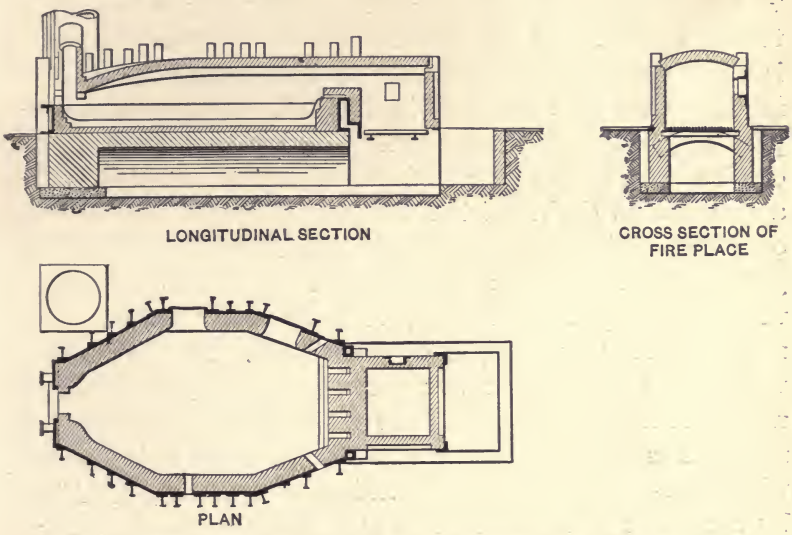

FIG. 26.—Details of the Fifty-ton Copper-refining Furnace.

work. The system is moved by a 10-H.P. series railway motor governed by the customary controller and geared to the driving head at one end of the chain. The molds proper are mounted on four-wheel carriages, the two pairs of wheels of which travel on pairs of rails of different gauge, so that a mold depends for its inclination from the horizontal upon the relative positions of the two sets of rails at the point of travel in question. The longitudinal axis of the mold is in line with the issuing stream of copper, but the line of passage of the mold, when the conveyor is in motion, is at right angles to this stream. The first condition per-

mits the mold to be rapidly filled without splashing or causing any pinching from unequal heating, while the second condition prevents the "heeling up" of the still liquid metal at the end of the mold, which would result from the long waves produced, were the motion in the other direction. The molds now filled are lowered horizontally, by means of the double rails, into water boshes, where they remain long enough to cool without becoming totally chilled. As the entire mold with casting in place is submerged, unequal contraction and consequent trouble in delivering true castings is avoided. As the conveyor proceeds, the link work carries the mold and contained casting out of the water and suspends them vertically for a moment to drain off the surplus water; it then moves over the driving head and dumps the finished wire bar on guides which lead to a small truck. (In the photograph the steam may be seen rising from the water bosh and the mold which is draining is clearly shown. As the picture was a time exposure it was necessary to stop the flow of metal from the launder.) The mold under consideration now passes beneath on the return trip, where it is daubed with bone-ash wash by an attendant and thoroughly dried by a current of hot air. The attendant in the pit marks on the inside of the mold the exact height to which it should be filled to give a bar of the standard dimensions.

The use of this casting device not only reduces the skilled labor to a furnaceman and his helper, but allows charges of 120,000 lb. to be poured in from four and a half to six hours, depending on the size of the bar made, frequently without a single bad casting.

The conveyors for the anode furnaces differ in detail but not in principle. The bosh is omitted as the appearance of the casting is no longer an object and the casting itself is so shaped that it cools sufficiently for rough handling without the use of water. The final cooling is usually

accelerated by a thorough wetting down with a hose after the anodes are stacked up. The anode is prevented from sticking in the mold by a pin, which automatically forces it out from below, and is delivered on a pair of arms very much as a sheet of paper is delivered from a jobber's printing-press. A pneumatic hoist now takes it with a pair of tongs and places it on a car specially designed for handling hot material. Each of these anode conveyors delivers without special effort a charge reaching sometimes over 150,000 lb. in three hours. This figure is from actual working results and not a special estimate. In the cake-copper conveyor a reciprocating train is substituted for the endless chain and unloading cranes are provided at each end, the cakes being taken off at one end of the train while the molds at the other end are being filled from the ladle situated midway between the cranes. The unloading device consists of two pneumatic hoists, one small and one large. The small one removes the frame in which the cake is cast and the large one then lifts the cake and carries it to a car placed conveniently on the industrial railroad.

The shot-copper well presents no particularly novel features. There is a launder direct from the furnace, and the issuing stream of metal is met by an air-blast and a thin sheet of water which break it up into the desired form; the shot falls to the bottom of the well and is caught in an iron basket which when full is lifted out by a crane and the shot dumped into a suitable car. Over 8000 lb. are handled at a time in the basket.

Silver Building.—In this building, which is of substantial brick construction, the slimes are separated into fine silver and gold by the sulphuric acid process. The slimes are trucked in barrels through the tunnel from the basement of the tank-house on to a hydraulic lift which carries them to the top of one end of the silver building. They are dumped on an 8-mesh screen, the coarse copper removed,

and the slimes washed through to a 60-mesh screen. The scrap copper from these screens is returned to the anode furnaces. The slimes are received in three settlers, which in turn deliver them to six agitators. The water from the settlers is siphoned to a settling system outside of the building. In the agitators, sulphuric acid is added, compressed air introduced, steam in the heating coils turned on, and the slimes and solution kept thoroughly agitated by paddles. After settling, the solution being run to the outside settling system and finally to the sulphate building to be worked into copper sulphate, the slimes now free from copper are sluiced into six drying tanks. Up to this point the slimes have been carried from tank to tank by gravity. When thoroughly dried by steam coils they are sampled, weighed, and taken to the furnace-room adjoining. They now contain from 40% to 50% silver. The slimes are now charged in water-jacketed cupel furnaces, of which there are two, each accommodating a charge of from 2000 to 3000 lbs. The resulting silver slabs are taken to parting kettles while the slag is melted with lead in a small reverberatory. The liquor from the parting kettle is carefully siphoned off, and after settling the entrained gold, it is run into precipitating tanks, the cement silver from which is dried in special ovens and melted into silver bars 990 fine, each weighing about 1000 oz. The doré bars from the parting kettles are re-parted in a third kettle and the resulting gold sediment carefully washed and melted in a small special furnace into gold bars 985 to 990 fine, weighing about 500 oz. each. All of the furnaces lead into a long flue with a series of dust-chambers terminating in an 80-ft. brick stack. The flue-dust is charged with the slimes into the cupel furnaces. The acid used is handled here, as elsewhere in the works, by compressed air, iron storage tanks being provided, into which the contents of the acid-tank cars are siphoned. Compressed air admitted to these

tanks forces the acid through a piping system to wherever required.

Sulphate Building.—The building is of brick and is devoted entirely to making copper sulphate. The foul solution is pumped from the storage well in the tank-house cellar, by means of steam injectors, to this building, where it is allowed to trickle through a series of oxidizing tanks containing shot copper, with a corresponding series of settling tanks interposed. Thus the excess of free acid is neutralized and the sediment thrown down and separated. The solution is then boiled to 38° or 40° B. and run into crystallizing tanks. There are four oxidizing, five settling, three boiling and 30 crystallizing tanks. The crystallizing tanks are built over a cellar similar to that of the tank-house, which allows a thorough inspection for leaks. At the end of the building is a washing pan and a revolving conical screen for sizing. The shaft carrying the screen is hollow and affords a means of introducing jets of hot air to dry the crystals while they are being screened. When the mother liquor, which is worked over several times, becomes so foul that the crystals are poor, it is sent to a series of iron precipitating tanks outside the building and the copper content recovered in cement form.

Blast-furnace Building.—The blast-furnace building, like the other furnace buildings, is built with a steel skeleton carrying corrugated-iron sides and roof. The main floor is at the ground level and is covered with checkered cast-iron floor plates. The charging floor above is of heavy planking carried by steel floor beams and is covered with plate iron around the charging door. The equipment consists of a 33×66-in. Fraser & Chalmers water-jacket furnace, with the usual dust-chambers terminating in an iron stack, a 30-H.P. shunt motor, a No. 6A Green rotary blower, a 4×10-in. Blake crusher, a bucket elevator, and a hydraulic lift. The material after crushing is carried by the bucket

elevator to a series of bins on the charging floor, near which are the usual charging scales. The hydraulic lift outside the building allows material to be trucked directly when desired. The slag is dumped on lowlands near the building, and the pigs of copper are loaded on cars of the industrial railroad to be taken to the anode furnaces. The flue-dust is charged back daily without briquetting. The furnace is used solely for the reduction of the oxide slag from the reverberatories. Oyster shells from the adjacent beds and burnt pyrites from chemical works in the vicinity afford advantageous sources of the lime and iron needed as flux.

Product.—The output of the works in refined copper is cast into wire bars, ingots, cakes, and slabs of various standard sizes as stated below. The quality of the copper is shown by the following average results, which were obtained from a number of lots recently tested and analyzed:

Physical Properties.			Composition.		
Percentage of Conductivity. Matthiessen's St'd. Annealed.	Tensile Strength. Hard-drawn to No. 12 B. & S.	Twists in 6 inches. Hard-drawn.	Cu. %	As. %	Sb. %
100.1	66,600	43	99.94	0.0020	0.0033

This checks closely the figure obtained (100%) for the average conductivity of all lots produced during a recent month, the determination of the conductivity of each lot being part of the daily work of the physical laboratory.

2. Guggenheim Refinery (Perth Amboy Plant).

The Guggenheim electrolytic works, now the Perth Amboy Plant of the American Smelting and Refining Company, were built in 1895 at Perth Amboy, N. J., for refining about 10,000 tons of argentiferous copper annually. These works were afterwards considerably increased in capacity and were recently replaced by a well-equipped larger refinery

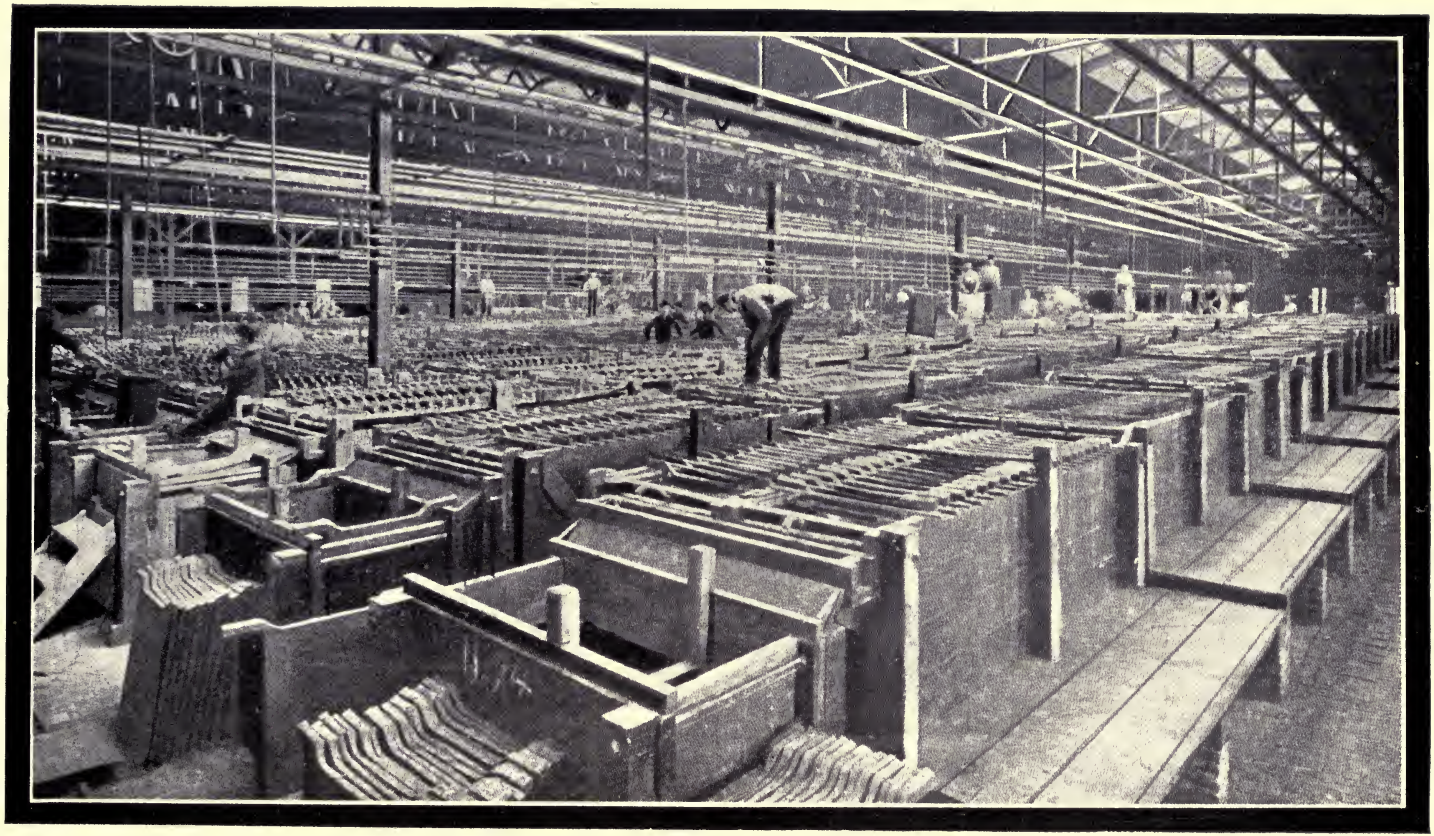

FIG 30.—Old Tank-house, Perth Amboy Plant.

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capable of turning out between 100 and 150 tons of electrolytic copper daily, or at least 36,000 tons annually, while the old refining plant, shown in Fig. 30, has been placed out of commission.

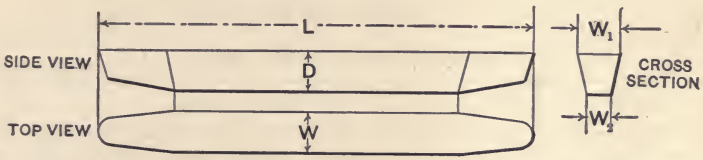

FIG. 28.—Shape of Wire Bar with Pointed Ends.

WIRE BARS, POINTED ENDS. (FIG. 28.)

Weight.	Dimensions in Inches.			
Pounds.	Length.	Upper Width, W_1.	Lower Width, W_2.	Depth, D.
77	$34\frac{1}{2}$	$3\frac{3}{8}$	3	3
100	35	$3\frac{7}{16}$	3	$3\frac{7}{16}$
135	38	$3\frac{5}{8}$	$3\frac{1}{4}$	$3\frac{5}{8}$
155	39	$3\frac{7}{8}$	$3\frac{3}{8}$	$3\frac{7}{8}$
175	53	$3\frac{1}{2}$	$3\frac{1}{16}$	$3\frac{1}{2}$
200	$49\frac{1}{4}$	$3\frac{7}{8}$	$3\frac{1}{2}$	$3\frac{7}{8}$
225	48	$4\frac{1}{8}$	$3\frac{7}{8}$	4
275	54	$4\frac{3}{8}$	$3\frac{7}{8}$	$4\frac{3}{8}$
300	51	$4\frac{3}{4}$	$4\frac{1}{4}$	$4\frac{3}{4}$
420	84	$4\frac{3}{8}$	$3\frac{3}{4}$	$4\frac{3}{8}$
575	88	$4\frac{3}{4}$	$4\frac{1}{4}$	$4\frac{3}{4}$

Most of the material to be treated is received at the works in the shape of either pigs of blister copper or anodes. The very rich gold and silver bearing blister copper from Aguas Calientes, Mexico, is melted down with low-grade copper bullion in reverberatory furnaces and partially refined before it is cast into anodes for the electrolytic treatment.

The new plant contains 816 depositing tanks and three 520 kw. generators, as against 360 tanks in the old plant and two 180 kw. generators. Before considering the new refinery, I will briefly describe the old refinery, with its

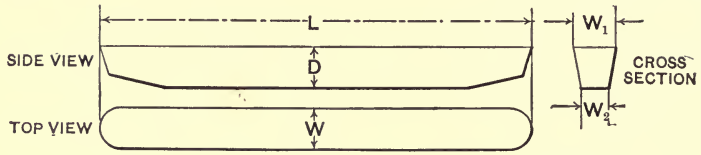

FIG. 29.—Shape of Wire Bar with Rounded Ends.

WIRE BARS, BLUNT ENDS. (FIG. 29.)

Weight.	Dimensions in Inches.			
Pounds.	Length.	Upper Width, W_1.	Lower Width, W_2.	Depth, D.
135	$37\frac{1}{2}$	$3\frac{5}{8}$	$3\frac{1}{8}$	$3\frac{5}{8}$
175	$40\frac{1}{2}$	$3\frac{15}{16}$	$3\frac{7}{16}$	$3\frac{15}{16}$
212	$40\frac{1}{2}$	$4\frac{5}{16}$	$3\frac{13}{16}$	$4\frac{5}{16}$
360	$61\frac{1}{2}$	$4\frac{1}{2}$	4	$4\frac{1}{2}$

SQUARE CAKES.

Dimensions in Inches and Corresponding Weights in Pounds.

Th'kness. Inches.	$1\frac{1}{2}$	2	$2\frac{1}{2}$	3	$3\frac{1}{2}$	4	5	6
Size, Inches.	Pounds.	Pounds.	Pounds.	Pounds.	Pounds.	Pounds.	Pounds.	Pounds.
14×17	111	148	184	221	258	295		
18×18	.....	201	251	301	352	402		
20×20	.....	254	317	381	445	508	635	
24×24	.....	.....	466	536	625	714	893	
26×26	.....	.....	531	644	752	860	1,075	
28×28	.....	.....	.....	729	851	972	1,215	1,458
32×32	.....	.....	.....	977	1,139	1,301	1,628	1,953
37×37	.....	.....	.....	.....	1,485	1,608	2,122	2,546
38×38	.....	.....	.....	.....	1,607	1,836	2,295	2,755
40×40	.....	.....	.....	.....	1,780	2,035	2,544	3,052
45×45	.....	.....	.....	.....	2,254	2,576	3,200	3,864

SLABS.

Dimensions in Inches and Corresponding Weights in Pounds.

Thickness. Inches.	$1\frac{1}{2}$	2	$2\frac{1}{2}$	3	$3\frac{1}{2}$	4	5
Size, Inches.	Pounds.	Pounds.	Pounds.	Pounds.	Pounds.	Pounds.	Pounds.
30 ×8	114	152	190	228	296	304	380
10 ×25	118	156	197	237	277	316	395
12 ×22	125	166	208	249	291	332	415
$24\frac{1}{2}$×8	93	124	155	186	217	248	310
48 ×$5\frac{1}{2}$	126	168	210	252	294	336	420
48 ×$4\frac{1}{2}$	102	136	170	204	238	272	340

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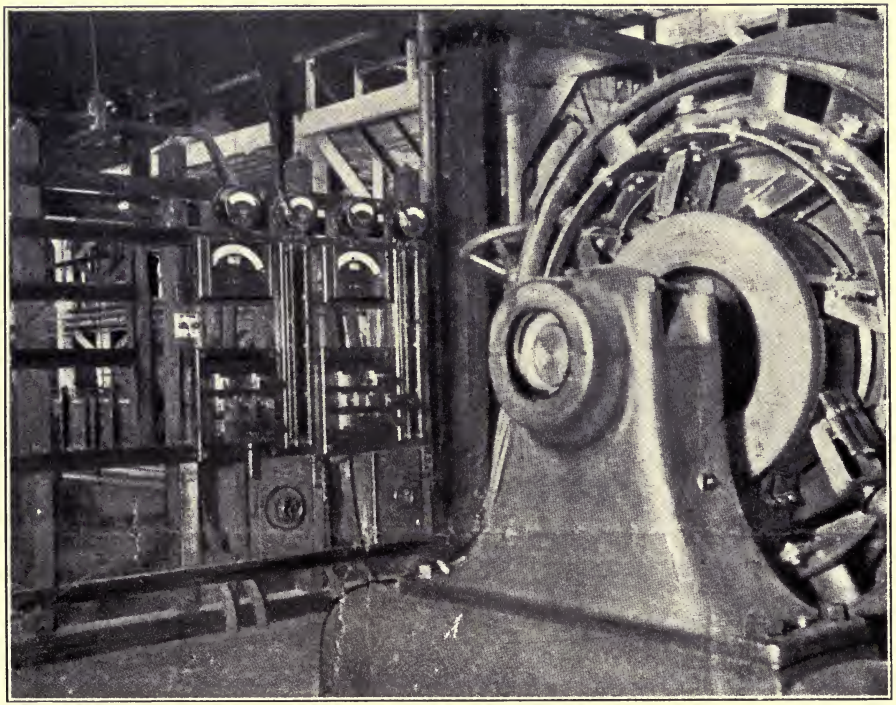

FIG. 31.—Generator of Commercial System.

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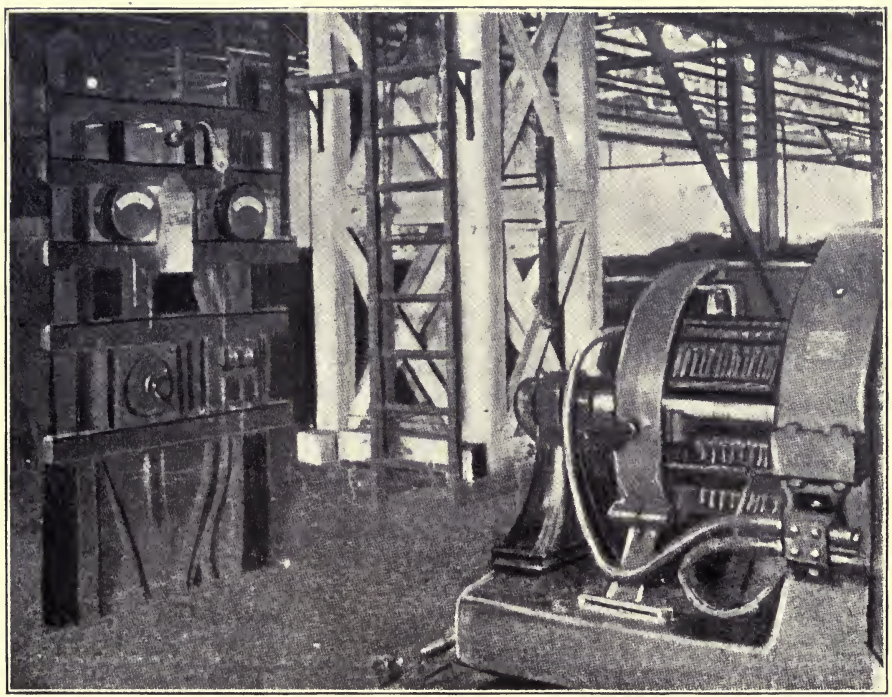

FIG. 32.—Generator of Cathode System.

30-ton tank-house and equipment, because of some of its interesting features.

A. *The Old Refining Plant.*—The boiler-house contained five Babcock & Wilcox boilers, rated at 125 H.P. each, and generating steam at 150 lbs. pressure, part of which was utilized for power purposes in the lead refinery.

Two Porter-Allen triple-expansion condensing engines, running at 250 r. p. m., drove two 180-kw. General Electric generators, one of which is shown in Fig. 31. These generators were of the 8-pole multipolar type, shunt wound, with smooth core armatures of the ring type, and delivered 1500 amperes at 120 volts.

Good satisfaction was given by woven-wire brushes, of which there were three to each brush-holder, or twenty-four in all, the cross-section of each brush being $\frac{7}{16} \times 1\frac{3}{16}$ in. The switchboard is shown in Fig. 31.

The cathode or stripping tank system was supplied by a 12-kw. General Electric generator, shown in Fig. 32, driven by a standard 25-H.P. Westinghouse engine. It was a 4-pole machine, with its field separately excited from a 110-volt power circuit, and delivered 1,000 amperes at 12 volts. The commutator was 24 inches in length, 14 inches in diameter, and contained 40 segments, each $1\frac{1}{16}$ in. wide. The brushes, 64 in number, were of carbon, 1.25 in. in cross-section, and contained a copper-wire core.

In the power-house there were also two 4-pole 40-kw. power generators and a 40-kw. 110-volt incandescent lighting generator.

The tank-house contained two groups of tanks: 1, those for refining proper, called the commercial depositing tanks, and 2, those for making starting sheets or cathodes.

In the cathode tanks rolled copper plates 0.1 in. thick were employed to receive the cathode deposit, which was permitted to become 0.04 in. thick, both sides of the rolled copper being thus plated. In former practice wood strips

formed a frame about three sides of the plates, but now grooves filled with insulating material serve the same purpose. The two surfaces of the plates were oiled and covered with graphite in order to prevent the cathode deposits from sticking, and the plates were placed in tanks between ordinary anodes. After the necessary thickness of copper had been deposited the sheets were stripped from the plates and were then ready for use as cathodes in the commercial tanks. There were thirty cathode tanks, each 8 ft. 6 in. long, 3 ft. deep, and 2 ft. 6 in. wide, supplied with current by conducting bars 1.25 in. square, placed alongside of each tank.

A general view of the tanks for the commercial deposition of copper is shown in Fig. 30. They were arranged in pairs, forming so-called double tanks, as shown in Fig. 33, and grouped in terraces, with a difference in level of about two inches between each row. The commercial tanks were constructed of 2-in. pitch-pine coated with P. & B. paint, each being 9 ft. 10 in. long, 3 ft. deep, and 2 ft. 6 in. wide. The electrolyte as prepared for the bath had in solution, by weight, 16% bluestone and 5% free sulphuric acid.

Each tank contained 22 anodes and 23 cathodes. The anodes were cast 2 ft. 6 in. long, 2 ft. wide, and 1.25 in. thick, and had the form shown in Fig. 34.

All of the 360 tanks were placed in series, and the plates of each tank in multiple. A copper conducting bar 1.75 in. square, afterwards replaced by a bar 1.5×3 in. in section, was supported along the outer edge of each tank, and a copper strip 1 in. wide and 0.25 in. thick was placed on top of the double partition wall between each pair of tanks. The tops of the cathodes were bent over and hung from $\frac{1}{2}$-in. square copper cross-bars. Fig. 35 illustrates how the electric current was distributed. It will be seen that the tanks of each pair are in series the same as the adjacent pairs of tanks.

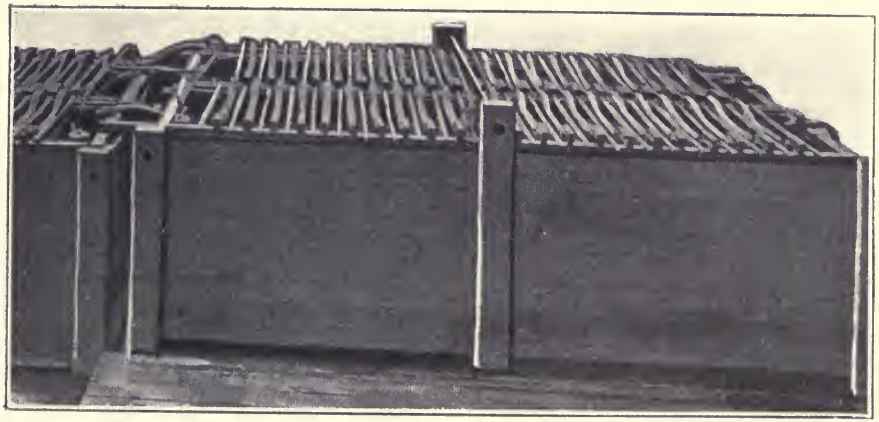

FIG. 33.—A Loaded Double Tank of the Commercial System.

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The anode and cathode plates were separated by about 1.25 in. The current density was about ten amperes per square foot (counting both sides of the anode plate), and it required about twenty-four days of twenty-four hours

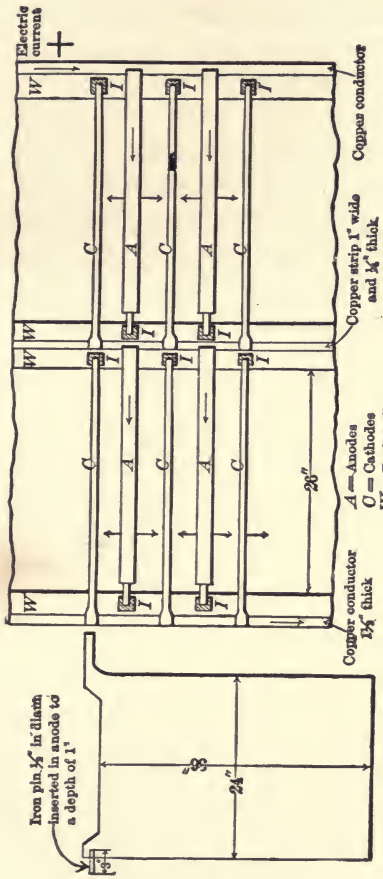

FIG. 35.—Top View of a Portion of Two Adjoining Tanks showing the Arrangement of Electrodes and Distribution of Current.

FIG. 34.—Improved Shape of Anode.

each to electrolytically transfer the copper of the 275-lb. anode to the cathode plate. The voltage, of course, depended only upon the ohmic resistance of the electrolyte, conductors, and plates. It averaged between 0.3 and 0.4 volt per

tank. With 356 tanks (four tanks were always out of circuit, having "slime" removed or being repaired) the voltmeter at the switchboard usually registered from 117 to 120 volts, with a current of 1500 amperes in use.

The deposited plates of pure copper were either sold as commercial cathodes or they were melted in reverberatories and cast into wire bars, plates, or ingots.

In the above-described refinery the copper treated was unusually rich in precious metals, and frequently carried as much as 300 to 600 ounces of silver and 3 to 4 ounces of gold to the ton of copper. The rich slimes accumulating in the bottom of the tanks were carefully gathered and screened from anode scrap through a perforated sheet copper screen, which was suspended in a tank in which the slimes were "boiled," or stirred up with acid so as to expose them to air as much as possible. The boiling tank was a lead-lined vat filled with hot dilute sulphuric acid (1 of acid to 4 of water) to a height reaching a little above the bottom of the screen, and provided with a perforated lead coil communicating with a Körting injector. The injector supplied both hot air and steam to oxidize and dissolve the impurities in the slimes and thus to concentrate the silver and gold during the boiling.

The slimes constituted at least 4% of the total weight of the anode copper refined, and after screening averaged 15% to 30% of metallic copper, 45% to 50% silver, 0.5% to 1% gold, and from 20% to 35% of impurities, such as arsenic, antimony, tellurium, bismuth, and lead, chiefly in a more or less oxidized condition. Although the boiling was not continued longer than eight or nine hours, the greater parts of the arsenic, antimony, and other impurities were dissolved and were then removed by siphoning off the solution and wash water from the silver slimes. The latter were then dried on iron pans in a hot-air chamber and sent to the lead refinery.

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About forty laborers, paid approximately $1.10 per day, were employed in the copper refinery. A comparatively large number of men were required because of the need of washing the anodes. This arose from the fact that the anodes ran unusually high in silver, and that they had to be removed from the tanks from time to time, and the adhering film of silver and other impurities scrubbed off in order to prevent polarization of the anodes and a reduction of their effective area.

The refinery occupied a floor space of about 200 feet square. Under a single roof of several bays it covered the engine and dynamo plant, the cathode and commercial tank system, and the crystallizing plant for the recovery of bluestone.

The cost of the above 30-ton refinery was approximately as follows:

Building (walls, roof, and trusses)	$50,000
Dynamos and fixtures	16,000
Two Porter-Allen engines and one small Westinghouse engine	11,000
Air compressor and pumps	2,000
Lead for lining tanks	12,000
Copper conductors	11,000
Lead burning	2,500
Tanks (woodwork)	10,000
Lumber for floors, etc.	2,500
Brick piers for tanks	3,500
Brick paving	1,000
Trolleys	2,000
Boiler plant (about 500 H.P.)	15,000
	$138,500

The above sum does not include cost of pipes for steam heating, nor of the tracks for transportation of material.

B. *The New Copper-Refining Plant.*—The new tank-house of the Perth Amboy plant was erected during 1901 and 1902. From 100 to 150 tons of electrolytic copper can be refined in it per diem, while the old tank-house could not treat over 40 or 50 tons daily. The refinery is at present running at about two-thirds of its full capacity, the remaining one-third being held in reserve. This will explain the surplus of generator power as compared with the actual daily output. The plant now comprises three 520-kw. generators and 816 depositing tanks, and produces about 100 tons of electrolytic copper daily.

The new refinery is said to embody an arrangement, patented and described by Mr. A. L. Walker, substantially as follows: The tanks are arranged with their proximate walls parallel and close together, and are supplied with current by leading-in and leading-out mains extending to the end tanks of a given series, these mains being of large and sufficient cross-section to carry the entire current supplied to all the tanks. Distributing bars of small cross-sectional area are supported between adjacent tanks, and the supporting projections of the anodes and of the cathodes in adjacent tanks rest freely on the same distributing bars, whereby electrical connection between anodes and cathodes of adjacent tanks is established through connections individually of small and insufficient area to carry the total current, but collectively of an area sufficient to carry said current. The supporting projections at one side of the anodes of the first tank and of the cathodes of the last tank rest freely on the leading-in and leading-out mains respectively. With this arrangement heavy conducting bars are entirely done away with between tanks, and the current is carried from tank to tank of the series by means of copper bars having, according to Walker, only 5% of the area of the large conductors, which are usually 5 sq. in. in cross-sec-

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FIG. 36.—Walker Fine-copper Casting Machines for Wire Bars and Ingots.

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tional area, if a 4000-ampere current is used. Thus the saving in copper by this arrangement, in carrying the current through the series of tanks and including the terminal conducting bars, is claimed by Walker to be at least 83% of the best former practice.

In casting anodes, wire bars, and ingots in the above refinery, four Walker casting machines of very large capacity, as shown in Figs. 36 and 37, are employed, and have given eminent satisfaction.

Anodes provided with a long and a short lug, as first used at the Balbach Refinery, are now employed at the Perth Amboy plant, instead of anodes of the shape illustrated in Fig. 34. In Walker's arrangement the lugs of the anodes in those depositing tanks not connected with the leading-in mains, which receive the current, rest simply on the knife edges of small, triangular copper bars, which are only about 0.5 sq. in. in sectional area, it is reported. It might seem that the ohmic resistance at the point of contact between lug and this conducting bar would be found to be very great when such heavy currents as 4500 amperes are supplied to the tanks with the usual voltage. This is not the case, however, which is rather remarkable.

The silver slimes collected in the above plant are first treated with acid, and then dried and sent to the lead refinery, where they are added to charges in a lead concentrator and enter into the metal cupelled into doré bars, which are subsequently parted by the Moebius process electrolytically.

3. The Anaconda Electrolytic Copper Refinery.

The first electrolytic plant at Anaconda, built during 1891 I believe, was altered and enlarged to its present design and capacity, chiefly under the direction of Mr. Hermann Thofehrn, in the years 1893–95. The present refinery

covers about 14,000 sq. yd., and consists of two sections, separated about 100 ft. for security in case of fire. The boiler-house and the silver mill are located respectively

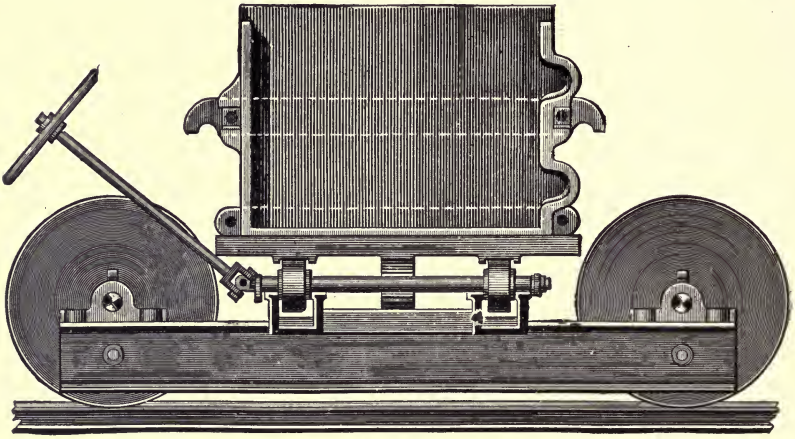

FIG. 38.—Side View.

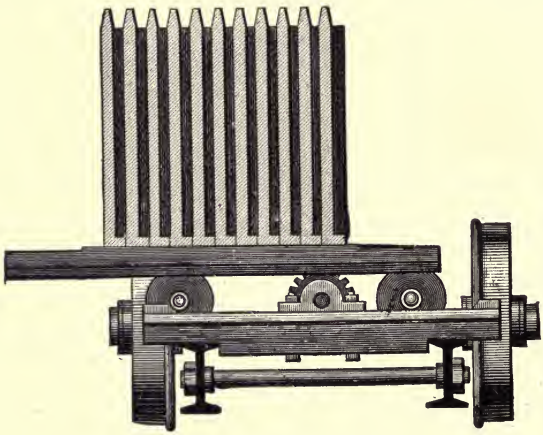

FIG. 39.—End View.

Hixon and Dyblie Car and Molds for Casting Anodes Direct from Converters.

200 ft. and 300 ft. distant from the tank-houses. These buildings, as well as the dynamo-room which adjoins the

FIG. 37.—Walker Anode Casting Machine

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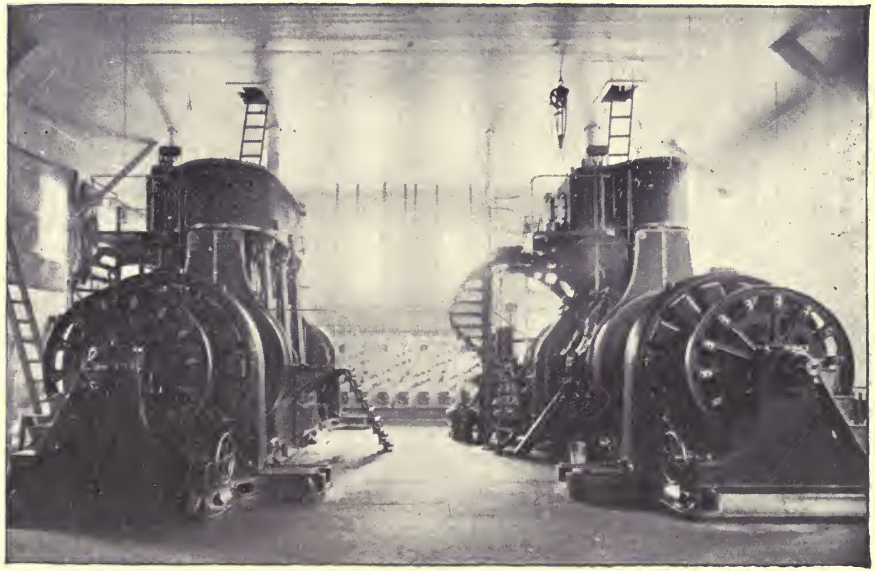

FIG. 40.—The Engine- and Dynamo-room of the Anaconda Refinery.

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tank-houses, are framed with timber, and covered on their sides, gable ends, and roof with corrugated iron. A large number of fire hydrants, with hose, are distributed throughout the buildings and are always kept in good working order by special watchmen. Much of the following detailed description is taken from the *Engineering and Mining Journal* of Sept. 19, 1896. I will consider the equipment of the boiler-house, engine- and dynamo-room, and of the tank-houses in turn, and then describe the actual working of the refinery.

The boiler-house contains three sets of two boilers, each of the Heine pattern, having altogether an evaporating capacity of 62,000 lb. of water per hour. Another set of two boilers of the same capacity serves as a reserve. All the boilers are connected by a large iron flue which carries the smoke and gases to a feed-water heater of the Green pattern, from which they are led to a brick stack 140 ft. high. The steam and feed-water lines are common to all the boilers, and the connections are so made as to permit of connecting or disconnecting any one of the boilers. The latter are supplied with American Co.'s underfed stokers, which have given great satisfaction. The ashes are sluiced to an elevator and finally dumped on the prairie adjoining the boiler-house. From the cars on a track in front of the boiler-house, the coal is dumped into large bins, from which a bucket elevator takes it into the supply bins suspended in front of the boilers. The coal drops from these bins to the feed-hoppers and is taken by the grates automatically and continuously. The feed-water is handled by two large Knowles pumps, each of sufficient capacity to supply all of the boilers alone. The water is taken from the hot well of the condenser and is delivered by the pumps through the Green heater to the boilers and acquires in this way a temperature of about 200° F. Twelve men are employed in the boiler-house.

The engine- and dynamo-room (see Fig. 40) contains a Corliss engine of about 800 H.P., a Westinghouse compound engine of 400 H.P., and two triple-expansion engines of 900 H.P. each. The two last-named engines are directly coupled to two dynamos each. This makes a total of about 3000 H.P. The Corliss engine runs the dynamos of the old section of the refinery at present by means of belting and shafting. The current for the electrolytic work is supplied by two 220 kw. Westinghouse generators, belt driven, and five 270 kw. Westinghouse generators, one of which is belt driven, while the other four are directly connected to the two triple-expansion engines. This makes altogether 1790 kw., corresponding to 2560 H.P. Out of this total, one generator together with the 400 H.P. engine are kept in reserve, being an electrical unit of 220 kw., equivalent to 315 H.P. This reserve unit can be switched over to any one of six circuits in case of an accident or repairs to any of the six generators regularly running. These generators are controlled from a central switchboard, to which all but two of the conductors lead.

Of the boiler output of 62,200 lb. of water evaporated per hour, the two triple-expansion engines, while producing at the normal rate 1080 kw. or 1544 H.P., consume at the rate of 15 lb. per horse-power per hour or 23,160 lb. of water. The double Corliss engine, while producing normally 490 kw., equal to 700 H.P. or 750 H.P. when the belting losses, etc., are added, consumes at the rate of 30 lb. of water per horse-power or 22,500 lb. per hour. Besides the generators for electrolytic work there are two dynamos for light and power, one being held in reserve. These require about 50 H.P., equal to 1500 lb. of steam. Then there is a 30-H.P. air-compressor which runs the acid pumps and consumes about 900 lb. of steam. The condensers for the Corliss and for the triple-expansion machines take another 1500 lb. of steam per hour. The

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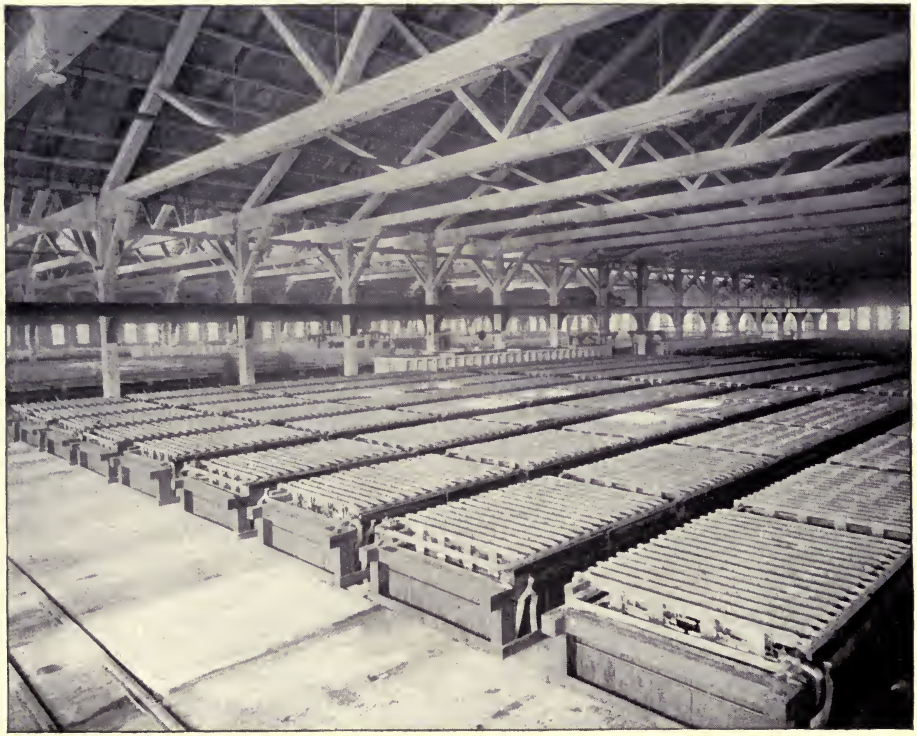

FIG. 41.—The Electrolytic Refinery of the Anaconda Copper Mining Co., Anaconda, Mont. Tank Service by Electric Traveling Crane.

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machinery mentioned in the aggregate consumes a total of 49,560 lb. of water, which added to 1500 lb. required for heating, makes 51,060 lb. of water which must be evaporated in the boilers. This is amply provided for, as the maximum capacity of the boiler plant, excluding the reserve boilers, is 62,200 lb. of water. The total amount of power consumed corresponds to a maximum production of 150 tons of electrolytic copper per 24 hours, or to about 17½ H.P. per ton of copper produced. This includes the power required for the lifting, the transporting, and handling of the copper, which is done by electric appliances, the manufacture of the cathodes, the operation of the silver mill, as well as the production of heat and light. Labor being more expensive in Anaconda than power, it is replaced wherever possible by machinery.

The refinery proper (see Fig. 41) is built in two sections, each tank-house covering a ground space of about 6500 sq. yd. and containing 600 electrolytic tanks. The tanks are 2.50 m. or about 8 ft. long, 1.50 m. or about 5 ft. 8 in. wide, and 1.00 m. or 3 ft. 3 in. deep. They are built on the self-insulating plan, that is, they are so constructed as to allow free access of air to their walls and bottom. A row of tanks is formed simply by covering a timber framework on the inside with common planks, and cutting it up into ten compartments by nine double partitions of the same material, so as to form a row of ten tanks. Each row is set on its own foundation, entirely separate from the others, and from the working floor. A large air-space is left between each compartment, so that all parts of the tanks, the sides as well as the bottom, are easily accessible. Every joint in the woodwork of the tanks and of the foundations is insulated by soaking with insulating material before the timbers and planks are put together. The lead lining of the tanks is protected by boards against injury from falling anode scrap. The electric conductors are placed on the

sides of the tanks and serve as supports for the electrodes. The bars are bent in the middle, so as to reach over two tanks, being positive on one and negative on the other tank. By means of this bend in the bars all screw connections are avoided between the tanks, and thus only the different rows require to be connected in the usual way. This effects an important saving of labor and power, as it is very difficult to maintain good joints for so heavy a current in an atmosphere charged with acid and steam, or moisture. To support the electrodes, flat iron bars are laid across the tanks and rest on the conductors. Copper hooks sustain the plates in the liquid and are hooked on these bars. Ten rows make a set of 100 tanks, and two sets make a system of 200. Each system fills a bay, and each bay of the tank-houses is provided with a complete outfit of machinery, tools, and appliances, making it entirely independent of the other bays and forming a complete unit by itself. As the composition of the crude copper changes in regard to its impurities and as the electrolyte has to be altered according to the amount of such impurities, it is absolutely necessary to be able to separate each system from the others. There are six systems of like capacity of 200 tanks, each being able to turn out between 25 and 35 tons of electrolytic copper per 24 hours as a maximum. All the tanks of each system are electrically connected in series and supplied with current produced by one generator. Each row of 10 tanks has its individual supply-tank for the circulation of the liquid. The circulation is established by having the rows built on an inclined plane. The liquid runs by gravity from one tank to the next until it reaches the last one, from which it falls to the collecting tank. The latter conveys the liquid to the acid pumps, working by air pressure, which deliver it to the distributor and from there to the small supply-tanks to begin the same course anew.

The three systems of the old tank-house are provided with overhead trolleys, one above each double row, by means of which the tanks are loaded with anodes and the cathodes are taken away. The full copper charge of a tank, weighing about four tons, is loaded up or unloaded in one operation. In the three systems of the new tank-house each bay has a single electric crane spanning its whole width, also designed to charge a full tank load at once. The reason why the first three systems were not provided with elecric cranes is that the old tank-house was not suitable for their installation, and the time given for the construction of the plant was too short to alter the buildings and to await the construction of the cranes. On the working floor of the bays runs an electric road of 20-in. gauge, by means of which all material is conveyed from the full-gauge railroad in the buildings to and from the tanks. The locomotives were designed by Mr. Thofehrn and built by the General Electric Co. Underneath the tanks runs another 20-in. road, which is used to convey the silver slimes to the silver mill.

Operation of the Refinery. The work in the refinery is carried out as follows: The men take the anodes from the railroad cars, transport them by the tank load over the scales, and place them on a rack. Here the supporting bars and hooks are laid over the anodes and the crane then picks up the charge, conveys it to the tank desired, lets it down therein, and at the same time places all the plates in their proper position. In the meantime another crew of men has placed a load of cathode sheets on a second rack, hooked on to the supporting bars and ready for use. These are now taken up by the crane and brought, like the anodes, to the exact place where they belong. After this the tank is filled with solution, the electric current started, and the refining work begun. The circulation of the solution and the electric current are stopped only in

those tanks which are being reloaded and then only for the time strictly required for this operation. This time, which includes unloading, cleaning, and reloading, bringing in of fresh material, its preparation, etc., hardly exceeds one hour for each tank. The unloading of the tanks goes on in about the same manner as the loading, i.e., the passage of the electric current and the circulation of the solution are discontinued, the crane takes out the full charge of cathode plates, and brings it down to a small, electrically driven, 20-in. gauge car, which conveys it to the railroad for shipment. The remnants of the anodes in the tanks are then taken out, the silver slimes are removed, and the tanks prepared to be loaded up again. A current density of 10 to 20 amperes per square foot of cathode surface is generally employed.

The crude material which the refinery treats is blister copper, containing 98% Cu on an average, and small amounts of arsenic, antimony, iron, lead, tellurium, selenium, besides about 110 oz. of silver and $\frac{1}{3}$ oz. of gold per ton. The blister copper was formerly, if not at present, cast into anodes direct from the converters, by employment of the car and molds shown in Figs. 38 and 39, which are fully described in U. S. patent No. 539,270 of May 14, 1895, granted to H. Hixon and J. Dyblie.

The large number of tanks and the high-cost price of labor at Anaconda necessitated a special means of controlling the refining operation. This control was secured by an automatic register, to which all tanks were connected by series of five tanks each. A yoke carrying two brushes slides over the different sections of a commutator-like device, making one complete turn in an hour, and these brushes bring into contact the terminals of each series of five tanks to register the volt meter. In this way all the tanks are controlled once an hour and the readings registered on paper automatically. This enables the man in

charge to see at a glance the condition of all the tanks in the refinery. He can see at once if any trouble is in any one of the tanks; of what nature the trouble is; when it started and how it developed. He is able, then, to point out to the foreman the tank in question, and this instrument keeps on recording when the man started to correct the trouble, how much time it took him to do it, and also how completely the work was done. The register costs $500 and the wiring about $1000.

The Anaconda Copper Mining Co.'s refinery in 1896 turned out, it is claimed, between 100 and 120 tons of electrolytic copper daily, and besides sent 80 to 100 tons of blister copper for refining to Baltimore. Although the plant was designed to handle 200 tons daily easily in an emergency, with the use of additional dynamos only, it has never reached this maximum, and is now producing at the rate of 84 tons of electrolytic copper daily.

In refining copper in Anaconda we have to consider the high price of labor, which amounts to nearly $3 on an average per day per man. The cost of fuel varies between $2.50 and $7 per ton, according to quality. Sulphuric acid costs 2.4 cents per pound in Anaconda, and other supplies are correspondingly high in price. We can safely state that expenses in Anaconda are generally about twice those at Eastern industrial centers. The refining work at Anaconda, according to Thofehrn, costs no less than $14 per ton of copper produced, including the saving and refining of the gold and silver slimes.

The total number of men employed in the Anaconda refinery is 120, inclusive of foreman, assayers, and clerks. While but 25 men are employed in the newer section of the refinery for a daily output of 50 tons, the older section requires about 50 men to refine the same quantity of copper, as the old tank-house was considered too weak to allow of the installation of all the modern improvements and

conveniences employed in the newer plant. In actual practice the combined output of both sections may be put at 100 tons daily, although there is sufficient tankage capacity for 200 tons, and the latter figure may be reached, according to Thofehrn, by simply increasing the electric current.

The electrolytic copper produced at Anaconda averages 98% in conductivity, Matthiesson standard; it has a tensile strength of 64,000 to 65,000 lb. per sq. in., can stand 80 twists in 6 in. of No. 12 wire before breaking, and has an elongation of 1¼%. All these measurements were taken on hard-drawn wire.

The anodes delivered to the refinery contain about 2% impurities, which, during the process of refining, go partly into the liquid and partly into the slimes. The impurities which enter the electrolyte are partially taken out on each turn of the electrolyte through the tanks. A certain amount of the impurities is allowed to stay in the liquid, however, while the purification process is regulated so as to limit the accumulation of these impurities only. The simple purification process used at Anaconda, necessitating the use of air and cheap chemicals only, is claimed to be superior to the old process of crystallizing, which is used in almost all Eastern refineries in treating impure solutions.

The Anaconda Co. in 1896 produced about 350,000 oz. of silver in bullion 999 fine and about 1500 oz. of gold as bullion 950 fine per month from slimes obtained in their copper refinery. These slimes were sent to the silver mill in lead-lined tank cars and treated as follows: They were first hoisted up to screens, washed with water, and all chips of copper, etc., taken out. The partly cleaned silver mud was then run out into boiling tanks, where it was freed from its copper contents, as well as most of its arsenic and antimony, by boiling with acid and steam. After running it on a filter and thoroughly washing it with water, the mud was transferred to large cast-iron pans and dried. A con-

sequent melting and refining in a reverberatory furnace reduced it to ingots or plates ready for the parting kettles. The furnace was charged with about two tons of the dried silver mud at a time, and after this was melted as rapidly as a wood fire would permit, it was refined and tapped into molds which moved on a small train in front of the furnace. The ingots or plates were then placed in the parting kettles, in which they were boiled with sulphuric acid. The silver sulphate obtained was siphoned off, diluted with water and silver from the solution precipitated on copper plates. The pure cement silver thus obtained was thoroughly washed, dried, and melted into ingots in furnace charges of two tons each. The ingots, weighing about 1200 oz. each, were assayed, numbered, weighed, and shipped away as bullion, generally 999 points fine. The gold was allowed to accumulate in the parting kettles for a month, when it was taken out, boiled in acid, washed, dried, and melted down into ingots, together with suitable fluxes.

The above slime-refining plant or silver mill was remodelled later, but the cost of producing fine silver and gold still remained very high. The slimes are at present (Sept., 1902) shipped in paper-lined boxes to the Seattle Smelting & Refining Co.'s works on Puget Sound and sold, as they can be refined there much cheaper than this could be done at Anaconda. The actual cost of refining at Seattle is not more than 1 cent per ounce of precious metals in the slimes. Contracts have been closed, I believe, by which the Seattle refiner pays for 98% of the silver, all of the gold at $20 per oz., and the copper in the slimes at the market price less 6 cents.

4. Nichols Refinery.

The Nichols Chemical Co. is operating electrolytic works in Brooklyn, N. Y., of an estimated daily capacity of 120 tons of electrolytic copper. There are probably six gener-

ators, each of 75 kw. capacity in the plant, and 120 tanks, placed in multiple series, with the plates therein arranged according to the series system. The tanks are 16 ft. long, 5 ft. deep, and 5.5 ft. wide, and built up of 1-in. thick and 4-in. wide planking. The anodes are from 0.25 in. to 0.38 in. thick, $4\frac{1}{2}$ ft. long, and 10 in. wide, and weigh about 65 lb. each. They are hammered straight by hand, and are suspended abreast in each tank, 6 anodes forming a row and about 100 rows filling a tank. As the rows are spaced about $\frac{7}{8}$ in. apart, the drop in potential between any two rows is probably as low as from 0.1 to 0.2 volt.

A serious drawback in the series system as applied at the Nichols Works lies in the much larger quantity of scrap copper, said to be 25% to 30% of the weight of the anodes, produced with this process than with the ordinary multiple system, although it possesses several advantages over the latter, such as the lower first cost of plant, and the smaller amount of electrical power required per ton of output.

5. Baltimore Copper Works.

The Baltimore Copper Works, operated by the Baltimore Smelting & Rolling Co., comprise two refineries located at Canton suburb, Baltimore, Md. Their total output is estimated at about 80 tons and their capacity 100 tons of electrolytic copper daily. Eleven 80 kw. generators furnish the required depositing current, which is supplied to about 540 tanks. The tanks in the smaller of the two refineries are arranged according to the multiple system, while those of the larger or Hayden plant are disposed according to the series or Hayden system, fully discussed heretofore under the caption: "Comparison of Refining Methods." In the multiple plant tanks of wood lined with lead which is itself protected by wooden boards soaked in paraffin, are used, while in the series system

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FIG. 42.—Pierce's Semi-mechanical Casting Apparatus

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FIG. 43.—The Tank-room of the Hayden Plant of the Baltimore Copper Works.

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FIG. 44.—Interior View of the Furnace-house of the Baltimore Copper Works.

[*To face page* 101.]

tanks of heavy slate coated with tar, which last longer, but are much more expensive than wooden tanks, are employed. The multiple anodes, cast of blister copper 1.25 in. thick, are supported by lugs of phosphor bronze.

Pierce's semi-mechanical casting apparatus, shown in Fig. 42, and Walker's casting machines, illustrated in Figs. 37 and 38, were first applied at these works.

Fig. 43 is a photographic view of the tank-house of the Hayden plant.

Fig. 44, the interior of the furnace-house, while Figs. 45, 46, 47, 48, and 49 show details of the electrolytic apparatus employed in the Hayden system.

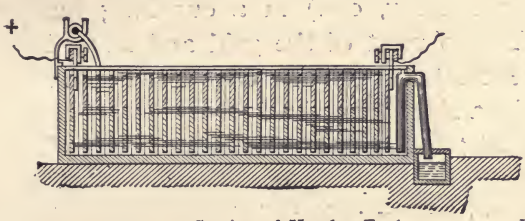


FIG. 45.—Section of Hayden Tank.

FIG. 48.—Section of Siphon.

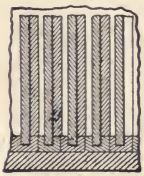


FIG. 46.—Enlarged Section showing Anodes with Deposited Copper.

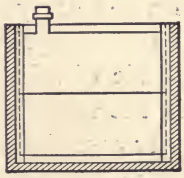


FIG. 47.—Transverse Section of Hayden Tank showing Anodes.

FIG. 49.—Grooved Slide.

Details of the Electrolytic Apparatus Employed in the Hayden System

The silver slimes obtained as a by-product, after screening, are treated in lead-lined tanks with dilute sulphuric

acid (1 part of acid to 4 parts of water) and air drawn in by a Körting steam injector during three or four hours. In this short space of time the greater portions of the arsenic, antimony, copper, and other impurities are dissolved, and are then removed by siphoning off the solution from the partly purified slimes. As the slimes contain lead sulphate and tellurium, a little bismuth and antimony, and the gold in a loose form unsuitable for economic parting, they are melted on a cupel hearth, at first without any flux. A small quantity of a brownish slag carrying about 20% of lead and less than 10% of antimony is then skimmed off, cooled, and picked over, so as to save the larger silver prills it contains. It is eventually added to molten lead (scrap, injured tank lining, etc.) in a cupelling furnace. Here the lead takes up most of the gold and silver in the slag, and is concentrated until its contents reach about 60% of silver, while a slag is raked off which is poor enough to be sent to a blast-furnace for reduction of its lead contents.

The second stage of the melting of the slimes consists in adding about 100 lb. of niter to the metal bath and skimming off a second slag. This slag is very rich in tellurium, containing as much as 20%, which could easily be extracted from the tellurite of sodium formed, so as to obtain possibly 100 oz. daily if there were any large demand for tellurium. The silver metal on the cupel now being practically free from impurities outside of a little copper, is cast into doré bars to be parted in the usual way.

Finally the copper contained in the dilute acid solution obtained in removing the arsenic, antimony, etc., from the impure slimes is precipitated by scrap iron and the precipitate is melted into impure copper bars, which are sold or given special treatment.

6. Great Falls Refinery.

This plant, belonging to the Boston and Montana Cons. Copper and Silver Mining Co., now a part of the Amalgamated Copper Co., at Great Falls, Montana, produces approximately 75 tons of electrolytic copper daily. Two 810 kw. generators, turbine driven, furnish the current to the tank-house, located about 500 yd. distant from the falls at Black Eagle dam, through huge conductors of cast copper 8 or 10 in. wide and 2 in. thick.

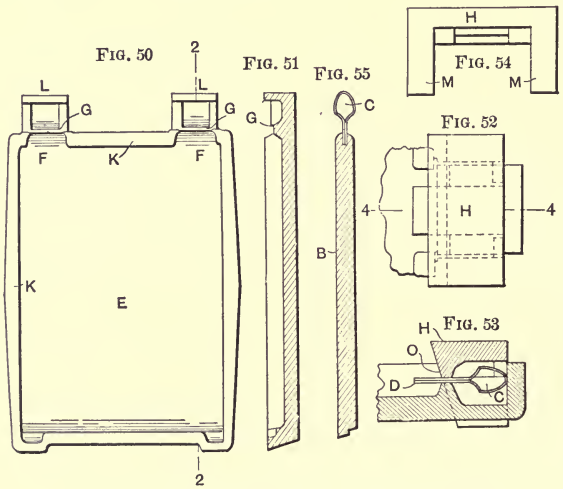
There are 324 depositing tanks in the refinery, each containing 20 cathodes and 21 anodes, arranged in multiple circuit. A current of high amperage (9000 amperes) is used at Great Falls, because ample and cheap power is provided. The density of the current is maintained, according to report, at from 30 to 40 amperes per square foot of cathode surface. This seems a dangerously high density to employ when good deposits are desired, although it enables the refiner to reduce the time required in turning out a given weight of cathodes to one-half, or one-third, of the time usually necessary. Moreover, such high densities are only practicable, it is believed, when the anodes to be refined are comparatively low in silver and gold, as at Great Falls, and the solutions are kept comparatively clear and pure. The tank conductors are about 6 in. wide and 2 in. thick.

The anodes are cast direct from the large converters employed in the Boston and Montana smelter, that is, the anodes are made from copper poured from ladles filled from the converters, and not from reverberatory anode furnaces, as is the usual practice.

J. T. Morrow, the superintendent of the Great Falls refinery, devised what he deems to be an improved anode, and invented the following form of mold for casting such

anodes. The nature of this invention will best be understood from a description of the accompanying cuts.

Fig. 50 is a plan view of the mold; Fig. 51 a cross-section on the plane 2 2 of Fig. 50; Fig. 52 a detail view showing a portion of the mold and clip-holder in place; Fig. 53 a cross-section of Fig. 52 on the plane 4 4; Fig. 54 an edge elevation of one of the clip-holders, and Fig. 55 shows in cross-section, on a plane corresponding to 2 2 of Fig. 50, the anode and its retaining-clip.



J. T. Morrow's Mold for Casting Anodes.

The anode *B*, Fig. 55, is of cast metal and provided with clips *C* of sheet metal, so formed that the ends *D* are cast into the anode and thereby secured. The mold *E* for casting the anode is shaped to the form required—such, for instance, as shown in Fig. 50—having, preferably, two lug-forming portions *F*. The wall *K* of the mold is much lower at the points *G* than at the other points and forms a low dam, upon which the ends *D* of the clips *C* rest, as seen in section in Fig. 53. A holder-block *H* is then placed on each clip and is adapted to fit snugly about the ends *D*

of the clip and form a continuation of the wall of the mold above the dam or bridge *G*, so as to confine the molten metal, while allowing the ends of the clips *D* to project into the molten metal and be thereby cast into the anode. Morrow prefers to arrange the holder-block and adjacent parts in the way shown in the drawings—that is to say, he provides projecting portions I on the mold *E* outside the low wall or dam *G*, and fits the weights or holders for the clips to these projections or extensions *L*, so that when in place the downwardly projecting lugs *M* lie on either side of the extensions and insure the proper placing of the clip-holders. The clip-holders are also provided with a downwardly extending edge or dam *O*, which comes opposite and registers properly with the dam *G*, leaving room enough between for the ends *D* of the clips *C*.

In using such a mold and clip-holder the clips are first laid in position and the holders then placed upon them. The molten metal is then poured into the mold *E* and flows into the lug-forming recess *F* of the mold. It surrounds and embeds the ends *D* of the clips, but is held in check by the fixed dam *G* and removable clip-holders *H*. As soon as the metal has cooled it is taken from the mold, with the clips *C* secured to it, as shown in Fig. 55.

If an anode breaks at or near its slugs during refining, it is hung upside down from the supporting bar on two copper-ring hooks passing through holes drilled through the defective anode. The quantity of scrap copper produced is thereby reduced.

The following ingenious machine for fastening flat loops on cathode sheets to secure a better method of their suspension than the method heretofore used was also designed by J. T. Morrow.

From cathode sheets, which are from $\frac{1}{60}$ to 0.1 in. thick, strips about 10 in. long and 3 in. wide are cut, bent at the middle, and together with the trimmed cathode sheets

fed by hand into the fastening machine. The latter first slits both the sheets and the loop at one stroke and in a designated spot in the shape of a cross, and then by means of a punch laps the double flaps produced by the slitting process over the cathode sheet, so as to make a secure fastening. The sheets can now be hung in the tanks by simply passing a copper rod through their two supporting loops. As the entire face of the cathode is thus made to hang within the liquid, its active surface is increased, and the circulation of the electrolyte at its top is not impeded, an important advantage over the usual method of suspending cathodes, which consists in bending their entire upper ends in a roll over the supporting bars.

Circulation of the electrolyte is effected by a terrace arrangement of the successive tanks, with a difference of about 2 in. in level between the latter, and the use of large connecting pipes. There is a complete renewal of the solution in a tank, say, every three hours. In raising the electrolyte from the receiving pump, direct-acting plunger pumps provided with improved rubber bucket lifts are used, together with "Montejus" or pressure tanks of the usual construction.

The following interesting method of purifying the electrolyte is reported as being used with success at Great Falls. It consists in treating the solution to be purified in special tanks and precipitating the impurities, chiefly arsenic and antimony, together with considerable copper, more or less loosely on copper cathodes placed opposite lead anodes, by very strong currents. There are 12 lead-lined purifying tanks (3 sets of 4 each) to 288 refining tanks, covered with hoods to carry off escaping fumes. The cathodes are about 0.1 in. thick, 30 in. wide, and 36 in. long, while the anodes are lead sheets of about the same size sweated on to the copper rods which support the plates. The precipitated impurities and copper partly hang on the

cathodes and partly drop to the bottom of the vats. These are cleaned out about every two months and the accumulated arsenical and antimonial mud, carrying from 40% to 60% copper, removed. The mud is finally reduced to impure bars in one of the refining furnaces in the works.

When the cathodes have become thickly incrusted with impurities or are otherwise rendered useless, they are melted down into cake copper or into certain brands of ingot copper, in which a small percentage of arsenic and antimony is said to be of little consequence, if it is not of direct advantage in increasing the fusibility of the copper.

The electrolyte purified by the above process is restandardized, returned to the refining tanks, and continued in regular use until it has become so highly charged with iron salts, etc., as to interfere with the copper deposition or cause the depositing copper to blacken. In that case only is the refinery solution withdrawn from circulation and pumped to the blue vitriol works, so that the amount of blue vitriol which it is necessary to handle in the works is kept down to a minimum.

Although an average of 75 tons of refined copper are produced daily in the above refinery, it is reported that only about 20 men, drawing wages of from $2.25 to $2.75 per diem, are regularly employed in the tank-room.

7. Balbach Refinery.

This electrolytic refinery, operated by the Balbach Smelting and Refining Co., at Newark, N. J., is the oldest in the United States. It was started early in the eighties and is still in active operation, with an output at present of about 45 tons and a capacity of 50 tons of electrolytic copper daily, produced with two 125-kw. generators and one of 300-kw. capacity; 430 electro-depositing tanks are employed.

The Balbach anodes are cast 36 in. long, 24 in. wide, and 1 in. thick, each having a long and a short lug, and weighing from 300 to 400 lb.

The cathodes are electro-deposited thin sheets of copper, 36 in. long and 24 in. wide, bent over copper suspending bars, whose bent-up ends rest on the tank walls or conductors.

Twenty anodes and as many cathodes are placed in a tank. The plates are all in multiple circuit and the tanks in series. As the tanks are all on the same level, the circulation of the electrolyte is effected by overflow through 1-in. lead pipes to launders placed below the floor level and feeding in the solution through lead pipes from an overhead feed launder near the middle of a group of four tanks, each of the four branches of the vertical feed pipe supplying a tank with solution.

The tanks are about 9 ft. long, 3 ft. wide, and 4 ft. deep, constructed of 3-in. plank and lead lined, two tanks being placed side by side, with one mutual dividing partition, and two with abutting ends, so that four tanks form a single group.

All the positive electrodes of a tank are placed in the same plane with the negative electrodes of the side-adjoining tank and vice versa, but the anode lugs of the first tank are insulated from the cathode bars of the second, when the cathode bars of the first are electrically connected to the anode lugs of the second, and vice versa. The connectors are flat pieces of copper used as supports. Light boards 4 or 5 in. wide are placed over all the connections so as to protect them from any dripping solution when the electrodes are lifted out of the tanks. The conductors are copper bars 4 in. by 0.75 in. in section, each bar being long enough to extend the length of the two tanks alongside of which it is placed. The bars are so arranged that their polarity alternates on the same side of a row of tanks.

In the latter a current density of 12 to 16 amperes per sq. ft. of cathode surface is maintained.

At the foot of each double row of tanks are placed two washing tubs for cleaning the anodes, and running over each double row are two lines of overhead rails with tackle for lifting purposes.

The slimes, containing silver, gold, bismuth, sand, etc., are cleaned up continuously, and the doré bullion eventually obtained is parted electrolytically.

When very impure copper is treated, the electrolyte may carry as much as 7 to 8 g. of arsenic per liter, and yet good cathodes for wire bars have been produced from anode material running as high as 5% in arsenic.

Regeneration of the solution is effected by periodically running off a portion of the electrolyte and replacing it by fresh solution. The copper, iron, and nickel sulphates are crystallized out from the portion withdrawn, and the mother liquor is boiled down so as to obtain arsenic salts, arsenious acid, etc. If the electrolyte carries much antimony, part of it precipitates as what appears to be gray antimonious oxide in the tank discharge launders.

The small quantities of nickel contained in the blister copper treated, and which concentrate in the acid electrolyte, are recovered as nickel salts by repeated fractional crystallization of the combined salts and a final removal of the remaining copper by electrolysis. The Balbach Co. was a pioneer in this method of producing nickel-platers' salts, for which it has found a ready market ever since 1891. Under the long and efficient superintendence of Mr. F. A. Thum and his son, Wm. Thum, it was also the first firm to introduce and successfully operate the multiple system of electrolytic copper refining in America, and employ the appliances and methods now generally used by electrolytic refiners. An ingenious tilting anode mold, designed by F. A. Thum, is in use at the Balbach Works. It consists of a

fixed standard with journals upon which the mold is pivoted and may be rotated. The mold itself is made up of two pieces: the anode mold proper, of the usual form for casting anodes, provided with a long and a short lug, and a separate piece with beveled edge, for forming the upper or head rim of the anode, which piece retains its place as long as the mold is kept in a horizontal position, and is hinged to the mold proper. When pouring copper into the mold, the latter is kept from turning over and discharging its contents by a clip, which is released as soon as the copper has set. The weight of the filled mold then causes it to tilt over and the head-piece to strike against the standard, whereupon it reacts in such a way that the weight of the anode itself forces out the head-piece by wedging against the beveled edge of the latter and finally allows the anode to slide from its mold into a truck or conveyor placed ready to receive it.

8. De Lamar Refining Works.

These works, located near Cartaret, N. J., refine blister copper from the Bully Hill Mines of California and the Tacoma Smelting and United States Mining Companies, and have a capacity for treating 50 tons daily. Current is furnished by one 520-kw. generator. The number of tanks is estimated at 408, and their arrangement is probably like that of the new Perth Amboy refinery of the American Smelting and Refining Co., as a royalty is being paid by the De Lamar Works, I understand, to Mr. A. L. Walker for the use of his patented arrangement of plant. About 10,000 oz. of silver and 200 oz. of gold are obtained daily in treating the slimes separated from the copper.

9. The Buffalo Refinery.

This plant forms part of the Buffalo Smelting Works, located in the Black Rock section of Buffalo, N. Y., and consists of an old and a new refinery.

At the Buffalo Copper Works about 60% of the Calumet and Hecla Co.'s enormous production of native copper concentrates is refined, argentiferous copper material running at least 15 oz. silver per ton, being melted down and cast into plates, which are sent to the electrolytic works. Practically all of the silver in the crude copper passes into the slimes or tank mud, and is periodically recovered by boiling the silver mud with sulphuric acid to remove the bulk of the impurities, refining it on a small furnace hearth and casting the silver into bars weighing about 1000 oz. each. The absence of gold from the argentiferous copper obtained by reducing the native copper ores of Michigan is remarkable and greatly simplifies the silver-parting process.

The old refinery contains 269 lead-lined tanks, approximately $10 \times 3 \times 3$ ft. in size. Its daily output is 6 tons of electrolytic copper, with a current measuring about 47 volts and 600 amperes. A current density of only three amperes per square foot of the cathode surface is used at Buffalo, as the management find it advantageous not to push the refining capacity of the electrolytic plant, especially as the cost of the power required quadruples with the doubling of the current density. Each anode plate weighs about 280 lb., and is cast about 1.6 in. thick at top, with three longitudinal strengthening ribs cast in, as ribbed anodes were found to hold together better than plain ones. The starting sheets are formed by deposition on both sides of copper plates lightly washed, it is said, with a dilute solution of iodine in naphtha.

The new 40-ton electrolytic copper refinery, built east of the old works, is furnished with power by a McIntosh-

Seymour engine, driving a Crocker-Wheeler generator, which is guaranteed to deliver a current of 300 volts and 1700 amperes when running at a speed of 126 revolutions per minute. There are reported to be 490 tanks in the new refinery, with a basement underneath the tank floor to facilitate inspection for leakages and emptying of the tanks. The circulation of the electrolyte is effected by a cascade arrangement of the tanks instead of on a level, as in the old refinery, the solution being pumped to the highest row of tanks and gravitating downwards. The anodes measure 29 in. long, 27 in. wide, and about 1 in. thick, and are provided with small lugs on top instead of large side lugs, which were formerly used. Electric traveling cranes and racks similar to those in use at the Raritan refinery will be used for charging the tanks with plates and removing the cathodes.

Each heat of refined copper is tested for the mechanical properties and for the electrical conductivity of the copper as follows: Representative sample bars weighing about one pound each are cast at the pouring of every furnace charge. Pieces of sufficient length from these sample bars are passed through small rolls and annealed at a dull-red heat in the muffle of an assay furnace whenever they become too hard. They are then pickled in dilute sulphuric acid, washed in water and passed through successive dies, finally being drawn into wire about 0.125 in. in diameter. These wires are numbered and constitute the samples used in the Siemens apparatus for making the conductivity tests. Good annealed copper wire 0.125 in. diameter should possess a conductivity of at least 98%, should stand about 55 twists before breaking, and should show a tensile strength of not less than 24 tons per square inch of cross-section, according to the usual standard.

The cost of electrolytic refining at the Buffalo works is reported not to exceed 0.3c. per lb. of crude copper, with current delivered at a cost of $27 per H.P. per year.

10. Blue Island Refinery.

This electrolytic plant, at Blue Island, Ill., is operated by the Chicago Copper Refining Co. It produces on an average 5 tons of electrolytic copper per day with two 64-kw. generators, delivering current to 250 tanks arranged in series, with plates in multiple.

The circulation of the electrolyte is either effected by means of two Montejus or collecting tanks, which are used alternately, so that as soon as one is full it is automatically closed, and a small air-compressor forces the solution up to the distributing tank again, or the circulation is effected by means of one pressure tank, by using a three-way valve, working automatically, which increases and relieves the pressure in this tank every 30 seconds. A circulation of 6 gal. per minute has been found convenient.

The Chicago Copper Refining Co. obtains about 3.75 lb. of slimes from every 100 lb. of anode copper. Formerly the washed, dried, and screened mud was shipped directly, or first melted into bars to avoid losses by dusting, and then sold to lead refiners, but it is now treated so as to recover doré bars, which are parted, to secure the fine metals, in the usual way.

B. Great Britain.

1. Bolton's Froghall Refining Works.

By John B. C. Kershaw.

This refinery, at Froghall, Staffordshire, England, and a smaller electrolytic plant at Widnes, in Lancashire, described in subsequent pages, belong to the firm of Messrs. T. Bolton & Sons, which was established in 1783 and had existed as a private company until June, 1902, when it was registered under the joint-stock company laws as Messrs. T. Bolton & Sons, Ltd., with a capital of $1,440,000.

The combined actual output of the Froghall and Widnes works for the years 1892 to 1896 was estimated to average 7000 tons per annum. Since the latter year no official figures are available for publication. It is reported that a portion of the plant at Froghall is used for depositing nickel and tin, but no authentic information can be obtained from the firm on this point.

The electrical power at the Froghall refinery is supplied by four 275-H.P. triple-expansion engines using steam at 150 lb. pressure. Each engine drives two dynamos of the Elwell-Parker type by rope gearing (see Fig. 56), generating 1500 amperes at 50 volts. The total capacity of this refinery is, therefore, equal to $\frac{1500 \times 50 \times 8}{1000} = 600$ kw.

The depositing plant at Froghall is represented by 550 vats, constructed in the usual manner of wood lined with lead, each measuring 48 in. × 30 in. × 42 in. deep. When fully charged each vat contains 10 anodes and 9 cathodes, and presents a total depositing surface of 126 sq. ft. The vats are arranged terrace-wise in order to facilitate circulation, and from 60 to 70 vats are worked in series. The electrodes in each vat are connected in parallel. Under normal working conditions 4 lb. copper are deposited per hour in each vat, and the maximum output of the Froghall works, when all the vats are in use, is 700 tons copper per month, or 8400 tons per year.

The anodes are cast from copper produced at the Widnes works, and they are allowed to remain in the vats six weeks. The sludge is worked for silver and gold in the usual manner.

The electrolytic copper obtained at this refinery is remelted, and is then worked up by the firm into wire (at the Oakamore Wire Works, situated near the Froghall Refinery), boiler tubes, rolled plate, etc.

FIG. 56.—The Generating Plant of Bolton's Electrolytic Works at Froghall.

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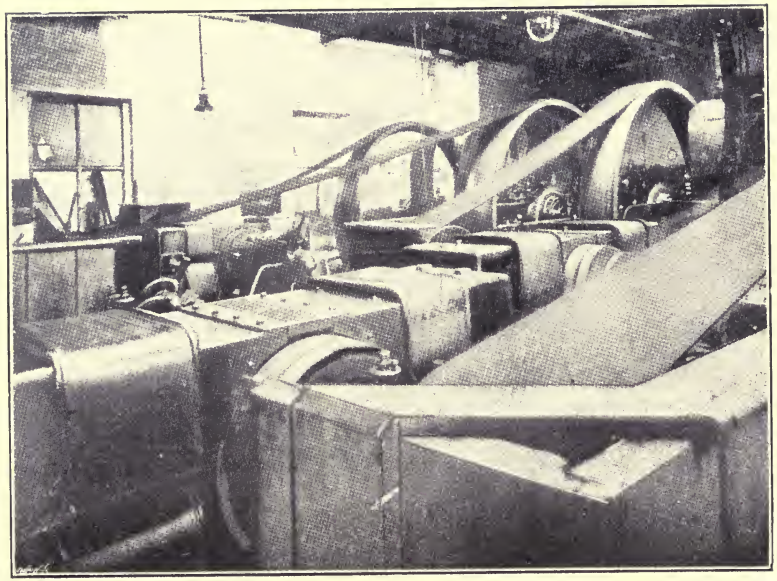

FIG. 57.—The Generating Plant of Bolton's Electrolytic Works at Widnes.

[*To face page* 115.]

2. Pembrey Copper Works.

The output of these works, belonging to Elliott's Metal Co., Ltd., Burry Port, South Wales, is about 130 tons per week. The number of vats in use is 1065. The electrodes are arranged according to the multiple process, which was invented by Mr. James Elkington, one of the proprietors of the Pembrey works, and was first installed on a commercial scale there in 1869. Elliott's Co. claims these were the first works in the world where copper by this process was produced commercially. A current density of 10 amperes is employed. Total power generated, 385 kw.; size of anodes, 10 in. wide by 24 in. long; size of cathodes, 4 in. wide by 24 in. long; voltage per vat, 0.3 volt.

The electrolyte contains 9 lb. of bluestone and 4.5 lb. of free acid per cubic foot, according to figures kindly furnished by the manager of the works.

3. Bolton's Widnes Refinery.

The Widnes plant, known as the Mersey Copper Works, of Messrs. T. Bolton & Sons, Ltd., is used for refining copper by both the fire and the electrolytic process. A large portion of the partly refined copper produced at these works is sent to the Froghall refinery for electrolytic treatment.

The electrical power for the Widnes depositing plant is provided by two Galloway engines, which drive by belt-gearing (see Fig. 57) four 75-kw. generators of the Elwell-Parker type. When running at 500 revolutions these generators deposit about 11.5 long tons of copper per 156 hours (Gore).

The vats (see view of interior of tank-house, Fig. 58) are said to be 4 ft. long, 2 ft. 6 in. wide, and 3 ft. 6 in. deep, and are placed in rows of 60 tanks in single series, with

gangways between rows. The current passes up one row, down the next, etc., and is maintained at a density of not exceeding 10 amperes per square foot of cathode surface. Each loaded tank contains 10 anodes and 9 cathodes, placed in parallel circuit.

The anodes consist of auriferous and argentiferous "bottoms," obtained by so-called "bottom smelting" of imported argentiferous "regulus" and of refined "coarse" copper.

In March, 1897, it was stated that Bolton's Widnes refinery was producing at the rate of 300 tons of electrolytic copper per month, although its maximum capacity under normal conditions is about 350 tons monthly or 4200 tons per annum.

4. Leeds Copper Works.

The following description and views of this plant, owned by the Leeds Copper Works, Ltd., Leeds, formerly the English Electro-Metallurgical Co., Ltd., are taken from an excellent article in *Engineering*, May 16, 1902, which is endorsed by the operating company.

The works are situated at Hunslet, Leeds, on the site formerly occupied by the Elmore works, which were erected to work the Elmore patents for the application of a burnishing tool to copper during the progress of the electrolytic deposition, but which did not pay for various reasons, although not, it is claimed, through any inherent impracticability in the processes.

The present concern has taken up the latter and the various properties of the old Elmore company, and is now working them with a large cash capital, and satisfactorily, it is asserted.

The new works are shown on the plans, Figs. 60 and 61. They consist chiefly of a boiler and economizer plant, an

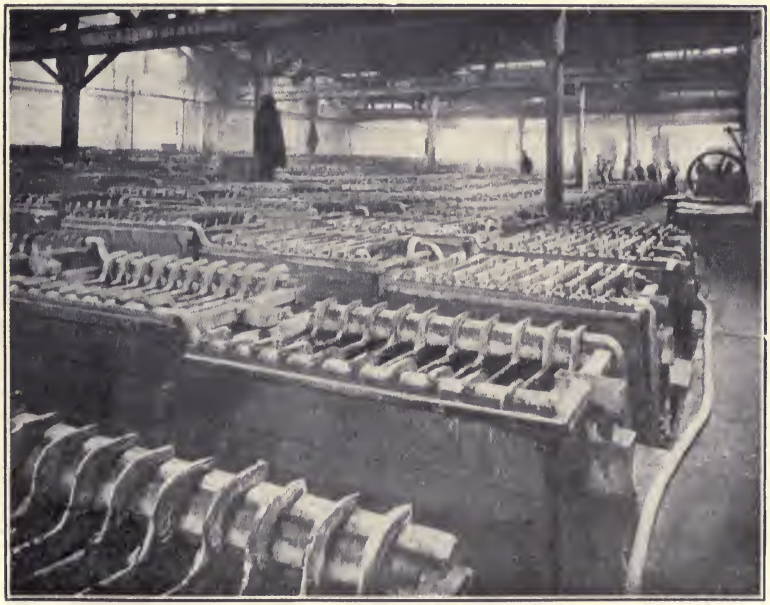

FIG 58.—Interior of Tank-house of Belton's Electrolytic Works at Widnes.

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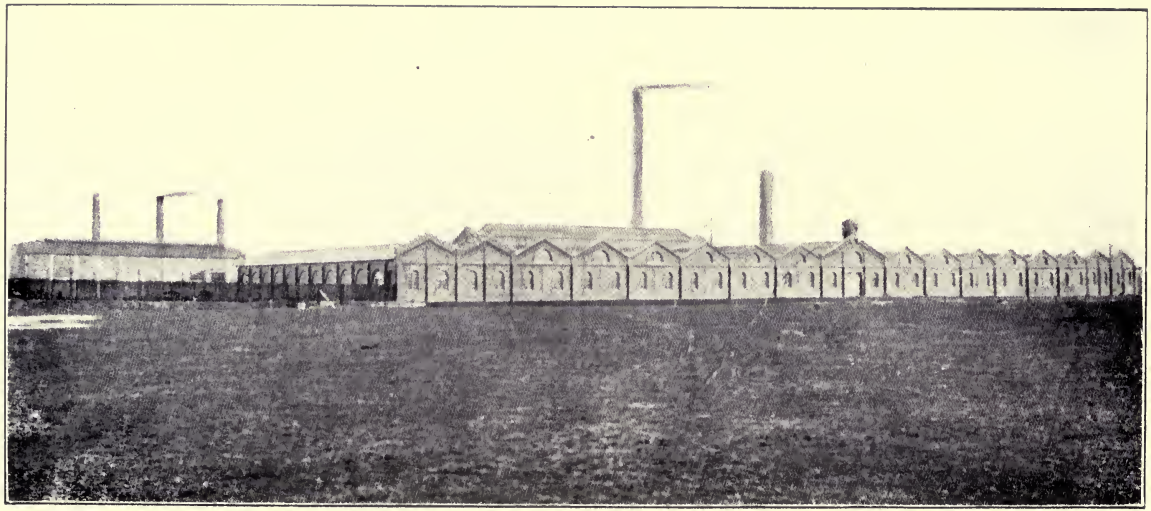

FIG. 59.—General View of the Leeds Copper Works.

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engine- and dynamo-house, buildings containing copper furnaces, a tank-house or depositing-room, and a shop containing draw-benches and other machinery. The Leeds

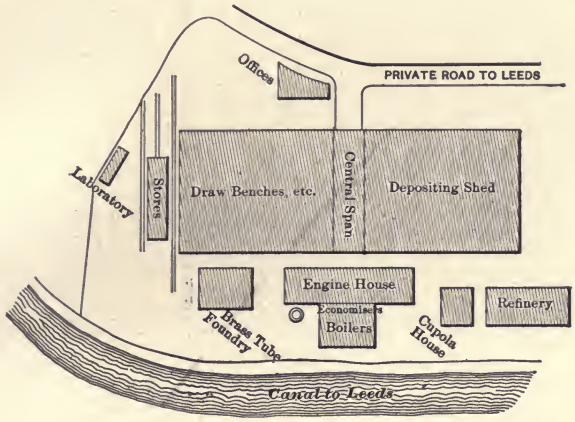

FIG. 60.—Map of the Leeds Copper Works.

works were built and equipped on the pattern of kindred works in France, which have been in operation for some years past at Dives, in Normandy.

The various shops at present cover 17 acres; they are connected with the Leeds-Liverpool Canal and with the Midland Railway.

The engine-room is shown in Fig. 62; it measures 215 ft. in length by 65 ft. in width, and contains:

(*a*) The depositing set of engines, consisting of four pairs of 250-H.P. Bollinck cross-compound condensing Corliss engines. The high-pressure cylinder exhausts into a receiver placed underneath the engine-room; the receiver supplies the necessary steam to the low-pressure cylinder, which exhausts into the condenser. Each pair of engines drives by belt transmission a 170-kw. Brown-Boveri generator for depositing.

(*b*) The power set, formed of three pairs of 400-H.P.

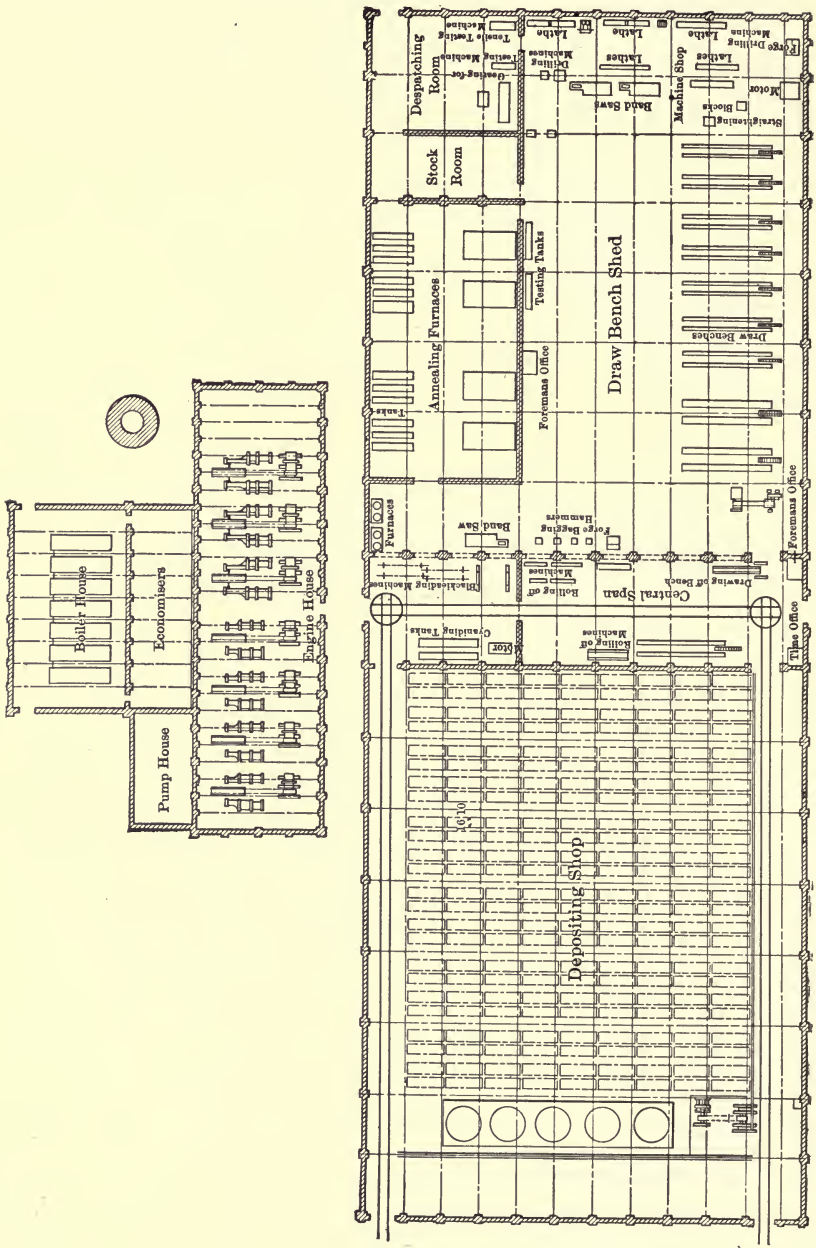

FIG. 61.—Plan of the Leeds Copper Works.

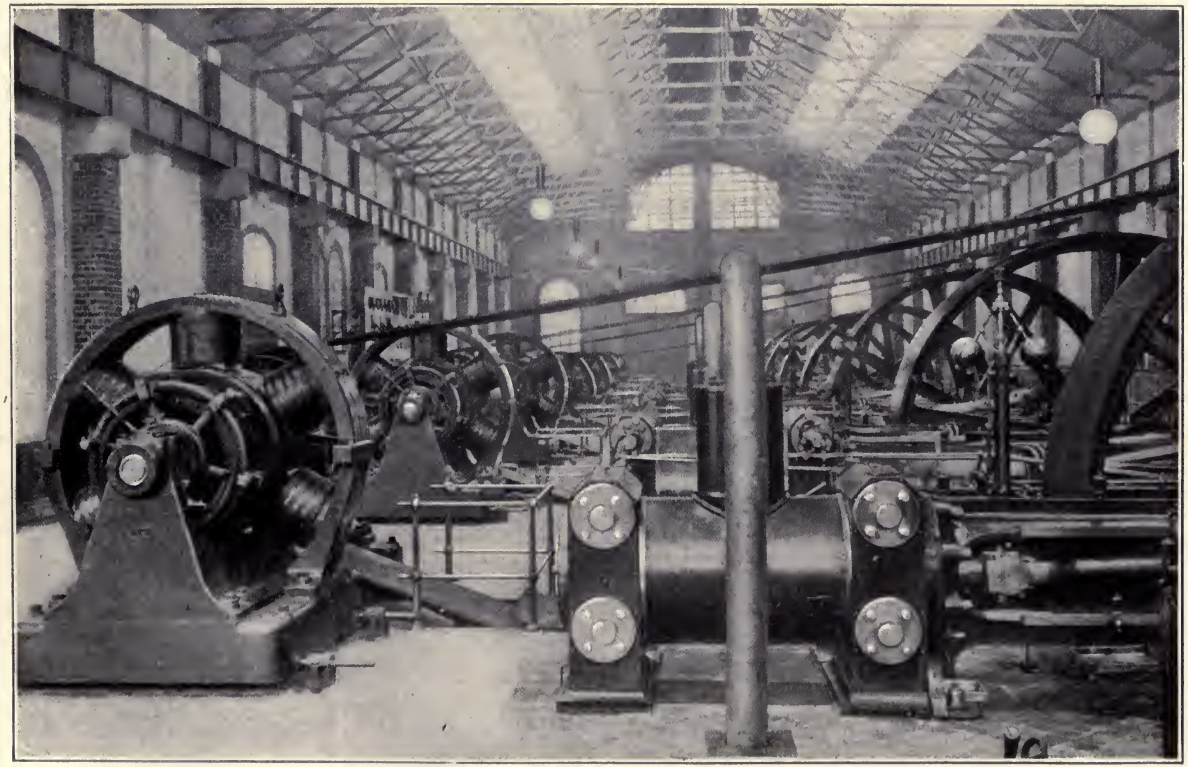

FIG. 62.—The Engine- and Dynamo-room.

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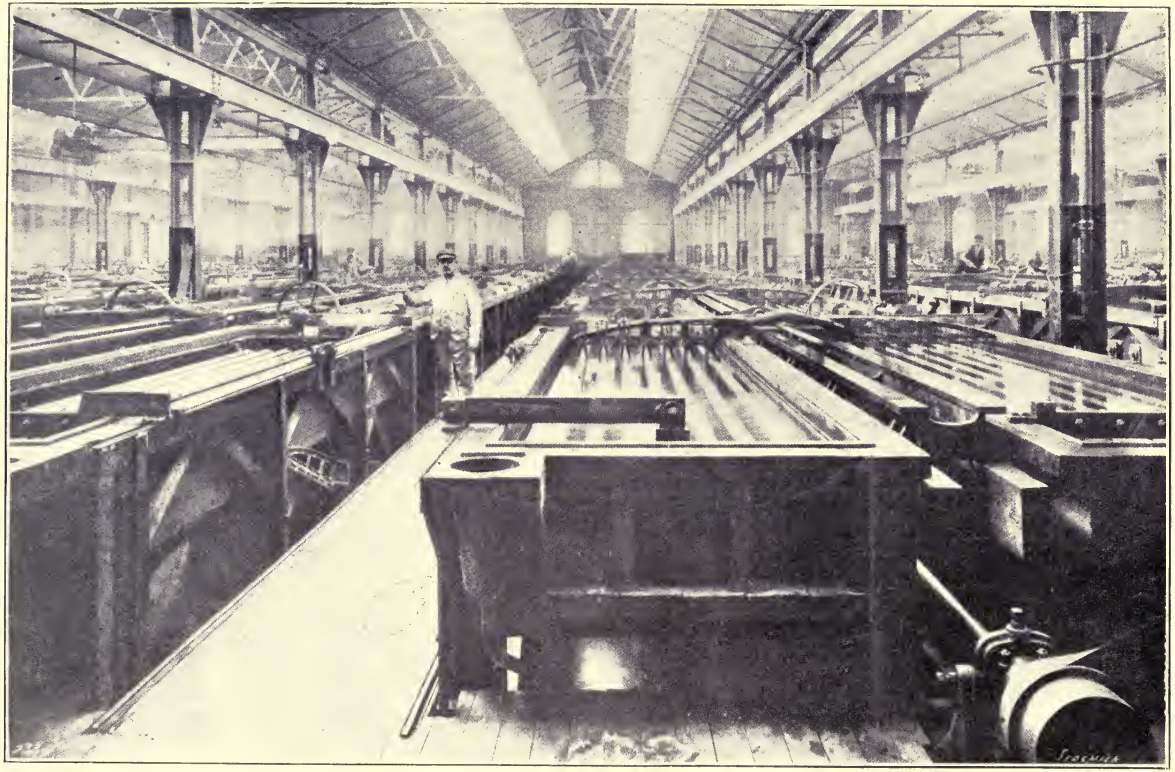

FIG. 63.—The Depositing Department.

[*To face page* 119.]

Bollinck cross-compound condensing Corliss engines, similar in design to the above, each pair of which drives a Brown-Boveri dynamo of 400-H.P. at 525 volts, and running at 325 revolutions.

(*c*) The lighting set, which consists of two 300-H.P. Willans high-speed engines, coupled direct to Elwell-Parker dynamos.

(*d*) The main switchboard, in two parts—one for depositing and the other for power—and the lighting switchboard.

The engines are supplied with steam at 140-lb. pressure per square inch, from seven Galloway 300 horse-power boilers, 32 ft. long and 8 ft. 6 in. in diameter, connected to a chimney 200 ft. high and 10 ft. inside diameter at top. They are fed by two Worthington feed-pumps. The feed-water is taken from the canal, but previous to being used in the boilers, it runs through a pulsometer "torrent" filter.

The boilers work in conjunction with seven economizers located in a space between the boiler-house and the engine-room. All the steam-pipes, valves, and connections are in duplicate.

The copper used in the depositing process is supplied to the works in the shape of 96% Chili bars or blister copper; this is treated, for the removal of arsenic and other impurities, in three refining furnaces of 12 tons each. The refined copper is then cast into trough-shaped molds, 13 ft. in length, for the production of the copper anodes. These are triangular in section, with slightly concave sides and vertices rounded off. They are cleaned with sulphuric acid and water previous to being placed in the depositing tanks.

The depositing department for the production of copper tubes and for the copper coating of rolls is illustrated in Fig. 63. It is located in a building 265 ft. long and 200 ft.

wide, which contains 216 acid sulphate-depositing tanks, in 24 rows of nine tanks placed end to end. Each of the six bays in the tank-house therefore covers four sets of nine tanks each, connected in pairs side by side for their mechanical operation. The plant is capable of a total weekly output of 75 tons. Two electric motors, one on each side of the depositing room, alternately drive an underground main shaft, placed underneath the front end of the tank rows. Link gearing, driven by the main shaft, gives the rotary motion to the mandrels (cathodes), around which the copper tubes are deposited; the same gearing also causes the backward and forward traveling of the burnisher frame.

For tubes up to 4 in. inside diameter the mandrels are of brass; for those above 4 in. inside diameter they are of cast iron, with a brass neck for receiving the current. The iron mandrels, previous to being used in the acid sulphate-depositing tanks for the production of copper tubes, are treated in an alkaline electrolytic bath containing copper anodes, and coated with a thin covering of copper. The alkaline bath is slightly heated in order to forward the depositing action. All the mandrels, before being placed in the acid sulphate-depositing tanks, are carefully covered with black lead, to facilitate the removal of the finished tube.

When starting work, the copper anodes are placed in the tank and the mandrels are nested alongside the former, but resting at both ends on insulated supports. Acid sulphate is then led into the tank by gravity from five cylindrical reservoirs on the side of the depositing room; the positive current is supplied through suitable lead conductors to the copper anodes and the negative current is led away from the mandrels by means of copper conductors and flexible brushes. The mandrels are caused to revolve, while agate burnishers, held in wood supports and fitted

to a frame placed transversely over the tank, are made to travel automatically up and down the whole length of the tubes, as they are being formed by deposition. The frame travels on paths on the sides of the tank, and is driven, as above mentioned, by gearing from the main shaft. The burnishing gives the tubes a uniform density and a perfectly smooth surface, it is claimed.

The works can manufacture tubes up to 4 ft. in diameter and 13 ft. in length, though practically there is no limit to the size. One of the current sizes is 12 ft. by 2½ in. outside diameter, and about No. 8 wire guage in thickness.

At the end of each operation, and previous to removing the mandrels with the complete tubes from the tank, a plug is raised from the latter, and the liquor flows by gravitation to three cisterns built below the floor level of the depositing room, and in which the sediment, containing gold and silver, has time to settle. These cisterns have a capacity of 12,360 cu. ft. The liquor is pumped up from a third cistern to the large cylindrical reservoirs above referred to, where it is treated for further use in the depositing tanks.

The depositing process being carried out with nearly pure copper, poor in precious metals, the sediment in the cisterns, which rarely carries as much as 6 oz. of gold to the ton of residue, is very easily handled.

Four of the bays in the depositing room are provided with hand-lifting gear; the manufacture of larger tubes and the copper coating of heavy rolls are carried out under the fifth and sixth bays, which are provided with overhead electric traveling cranes, each of 5 tons capacity.

When the copper-coated mandrels are removed from the depositing tanks, they are carried to an adjoining machine-shop and placed in a tube-expanding machine, in which they are made to revolve under two friction rollers,

which travel along the whole length of the tube. They are then placed in a power draw-bench and held down. One end of the mandrel is fastened to a grip, and the latter, on being hooked to a flat-link chain drawn by a sprocket wheel, removes the mandrel from the inside of each tube.

This shop contains tube-expanding machines, driven by belt transmission from an overhead shaft, draw-benches driven by an underground shaft, and numerous other tools, such as power-hammers, saws for cutting the tubes to length, and lathes for turning the mandrels. Overhead travelers serve all the bays in which heavy work is performed.

Many of the tubes manufactured are drawn in the draw-benches through dies, in order to give them the required dimensions to meet certain specifications. This drawing has the effect of hardening the copper. The tubes are then placed in a reverberatory furnace, in which they are heated to a low red heat, after which they are quenched in water and cleaned in acid and water baths.

The machine-shop contains the required plant for testing the tubes by hydraulic pressure, and for determining their tensile strength.

Besides the tubes, calico-drying cylinders, calico-printers' rolls, paper-makers' cylinders, seamless copper cylinders for hydraulic machinery, pump liners, and hydraulic ram covers are produced.

The copper tubes made by this process are claimed to be able to stand, without showing any defects, the following mechanical tests: Doubling close cold and then doubling over; doubling close cold and opening out; creasing up on end, expanding, flanging (diameter across the flange being equal to three times the diameter of the tube), reducing the doubled edge of the tube to a knife-edge, and turning back flat in its hard state, without breaking.

The Leeds Copper Co. is on the Admiralty list for copper

tubes and pipes other than steam pipes, and the latter are subject to the British Board of Trade tests.

A plant for the manufacture of drawn brass tubes from the copper tube scrap, etc., is now being erected at Hunslet, Leeds. The output of this new plant is intended to be 25 tons per week.

The Elmore process is also being worked by the Société d'Electro-Metallurgie de Dives at Dives in France, and by the Elmore Metall A. G. at Schladern, near Cologne, Germany.

5. Vivian Refinery.

This plant forms part of H. H. Vivian & Sons' Copper Works, it appears, and must not be confused with the Hafod Copper, Cobalt and Nickel Works, owned by H. H. Vivian & Co., also of Swansea, Wales. The refinery has an estimated daily output of 8 to 10 tons of electrolytic copper.

In the electrolytic process either the whole of the coarse copper, largely received in the shape of "regulus," is refined direct, or else auriferous and argentiferous "bottoms" are produced by fire methods, and these bottoms are then refined electrolytically. Various makes of generators, Elmore's, Gulcher's, Crompton's and Edison-Hopkinson's, furnish the required current.

The following are claimed to be characteristic features of the refining methods adopted: The anodes are cast shorter and narrower in size than the cathodes, in order to make the distance, and therefore the electrical resistance between the edges of adjacent electrodes in the tanks greater than that between other portions of these plates, and thus lessen the current density at the edges in comparison and check the tendency of the copper to "tree" across.

By setting the molds a little out of the level, the anodes are cast about $\frac{1}{8}$ in. thicker at the top than at the bottom,

so as to check the tendency of the anodes to be eaten away at or near the surface of the electrolyte and diminish the production of scrap copper.

In stripping the cathode sheets from their copper pattern plates, the latter are varnished with a weak shellac varnish containing about 1 lb. of shellac to 1 gal. of alcohol, which prevents the deposited copper from sticking and at the same time is not sufficiently thick to insulate the cathodes from the passage of the current. The edges of the pattern plates are dipped in "Brunswick black," and the sheets of copper are then easily detachable from the plates.

The voltages in the tanks are preferably tested with an ordinary electric bell, especially wound so as to ring at its ordinary loudness when the tanks are at the correct voltage. If the bell rings more or less loudly, it is a sign of either dirty contacts or of short-circuiting in the particular tank under test, a method of inspection which appeals more to the average Welsh workman, it is claimed, than reading a delicately pivoted and expensive voltmeter.

6. McKechnie's Refinery.

This plant, a part of McKechnie Brothers' Metal Works at Widnes, produces about 9 tons of electrolytic copper daily. It is believed to contain 234 depositing tanks and three dynamos, generating 1500 amperes at 50 volts.

C. GERMANY.

1. Hamburg Refinery.

In 1895 the estimated production of the North German Refinery at Hamburg was 1728 tons of electrolytic copper annually or 4.8 tons per diem; at present the output is probably nearly 10 tons daily. The plant was started in 1876.

There are 600 depositing tanks in the above refinery, each containing a large number of very narrow cast anodes. Its able manager, Dr. Emil Wohlwill, who formerly had considerable trouble in his two plants on account of crystalline growths on or "sprouting" of his cathodes, has now succeeded in almost entirely overcoming this difficulty by interrupting the electrolytic process for half an hour daily and arranging that the electrolyte contains a small but sufficient quantity of salt or chloride in addition.

Schnabel gives a table in his "Handbook of Metallurgy," p. 266, showing that with each 12-H.P. Gramme dynamo, delivering a current of 300 amperes at 27 volts tension to 60 tanks, the Hamburg refinery deposits 1984 lb. of copper in 24 hours. The effective cathode area of each tank is nearly 162 sq. ft., a current density of 1.85 amperes per sq. ft. is employed, and about 6.87 lb. of refined copper are deposited for each horse-power hour.

It is stated that the anode slimes are reduced in a small blast-furnace with litharge to a copper-lead alloy, and that the latter is then cupelled with argentiferous lead.

The Hamburg refinery is certainly the largest electrolytic plant in Germany and probably one of the best arranged.

2. Mansfeld Electrolytic Copper Works.

The product of this plant, operated by the Mansfeld Kupferschiefer-bauende Gewerkschaft of Eisleben, is estimated at about 5 tons of electrolytic copper daily. In 1886 the approximate production was 734 tons annually or 2 tons per diem. Wilde's dynamos are employed for generating the current, which is distributed among the tanks and electrodes by the ordinary multiple system.

The Mansfeld Copper Co., according to Kershaw, established the first electrolytic works outside of England, although Schnabel claims this honor for the Hamburg re-

finery, and started their small refinery at Eisleben in 1872, according to Kershaw, and in 1879, according to Schnabel.

The anodes consist of so-called "bottom copper," rich in precious metals, obtained from roasted raw matte by the process of "extra concentration smelting." The latter process, at the same time, produces a rich slag, which is retreated, and an extra concentrated matte, which runs about 78.2% Cu, 0.47% Ag, 0.38% Pb, 0.48% Fe, 0.01% Mn, 0.27% Zn, 0.35% Ni, 0.06% Co, and 19.68% S, and is desilverized by the Ziervogel process and refined like ordinary concentrated matte to a refined copper, containing 99.75 to 99.8% Cu and 8 oz. of silver per ton. The electrolytic copper produced, being free from silver, is of a slightly higher grade than this metal and of greater conductivity.

3. Oker Electrolytic Refinery.

This plant, operated by the Koenigl. u. Herzogl. Communion Huettenamt at Oker, produces about 5 tons of electrolytic copper daily with water and steam power, rated at 100 H.P. It was started in 1878. The Oker anodes are 39 in. long, 20 in. wide, and 0.6 in. thick. The cathode pattern plates are made of electrolytic copper less than 0.12 in. thick, painted over with petroleum spirit and their edges coated with paraffine.

The cathode-starting sheets are suspended from the conductors by means of copper strips 0.8 in. wide and 0.08 in. thick, riveted to the sheets and protected where immersed from the action of the solution by a coating of paraffine.

According to Schnabel, three different types of Siemens & Halske dynamos are employed at Oker, varying in tensions from 3.5 to 30 volts, according to the number of tanks to which they furnish current, and in current strengths from 120 to 1000 amperes. They each deliver an effective power at the terminals of between 3500 and 4800 watts, and

each deposit between 551 and 661 lb. of copper in 24 hours. The arrangement of electrodes and conductors in a typical

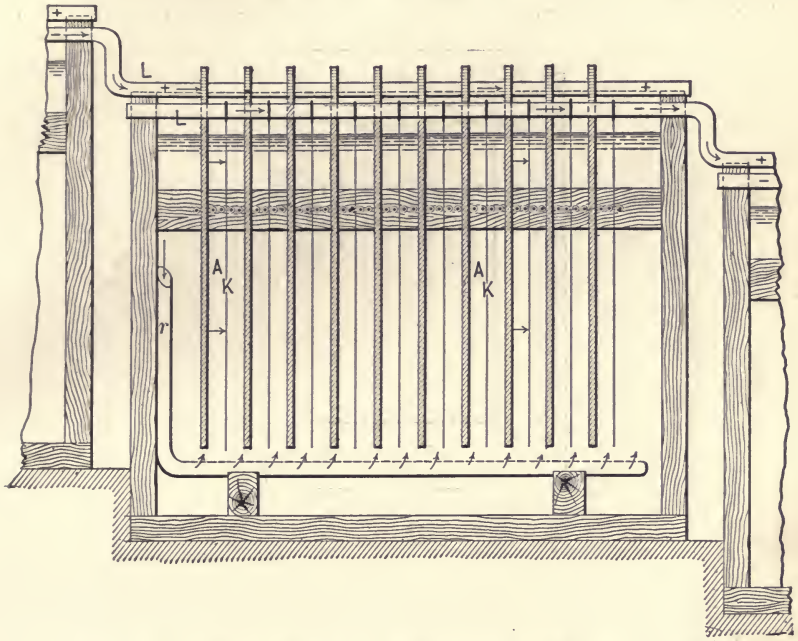

FIG. 64.—Lengths Section of Electrolytic Tank, Oker Refinery.

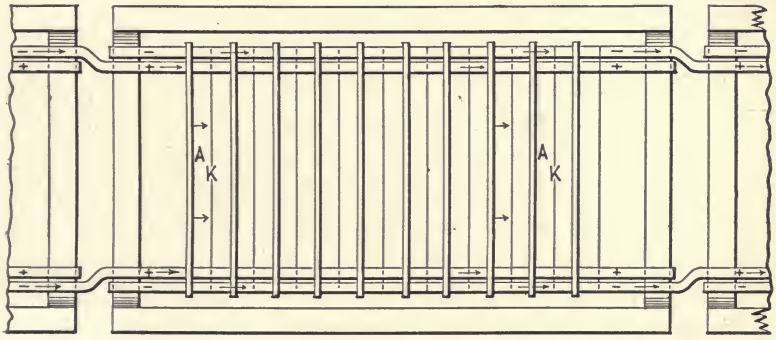

FIG. 65.—Plan View of Electrolytic Tank, Oker Refinery.

tank is shown in the subjoined cuts, Figs. 64, 65, and 66 (from Schnabel's "Metallurgy).

The anode slimes are treated by the so-called rich bullion smelting process in the blast-furnace, and a product is obtained consisting of rich lead bullion, matte, and speiss.

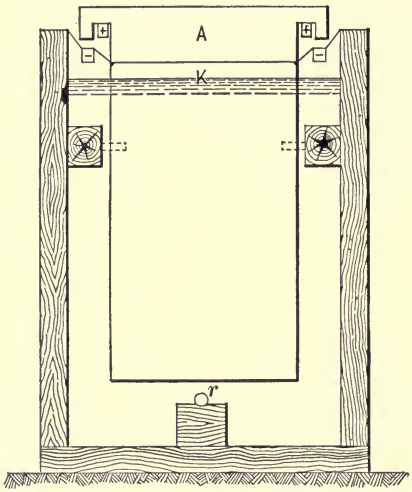

FIG. 66.—Cross-section of Electrolytic Tank, Oker Refinery.

This lead bullion is then cupelled and parted in the ordinary way to recover the precious metals.

4. Goslar Electrolytic Refinery.

This plant, belonging to Borchers Bros., at Goslar, in the Harz Mountains, produces about 1 ton of electrolytic copper daily, it is reported. About 1892 the proprietors of the above works provided their electrolytic tanks with a novel apparatus, claimed to have been invented by Werner von Siemens in 1884 or 1885, for effecting the circulation of the electrolyte. Within a large lead pipe, *b*, which is open at both ends and which connects the center of the bottom of the electrolytic bath with the surface of the liquid at one end of the tank, a fine jet of air is blown into the liquid some distance from the surface of the latter by means of

a glass tube, *g*. The column of fluid above the lower end of the glass tube *g*, mixed with small air bubbles, grows lighter in sp. g. than the bulk of the liquid in the tank; it therefore rises and flows over the upper end of the pipe *b*, while at the lower end of the same pipe a constant current of heavy liquid rushes in. An almost noiseless but very lively circulation is the result of this process. To prevent waste of

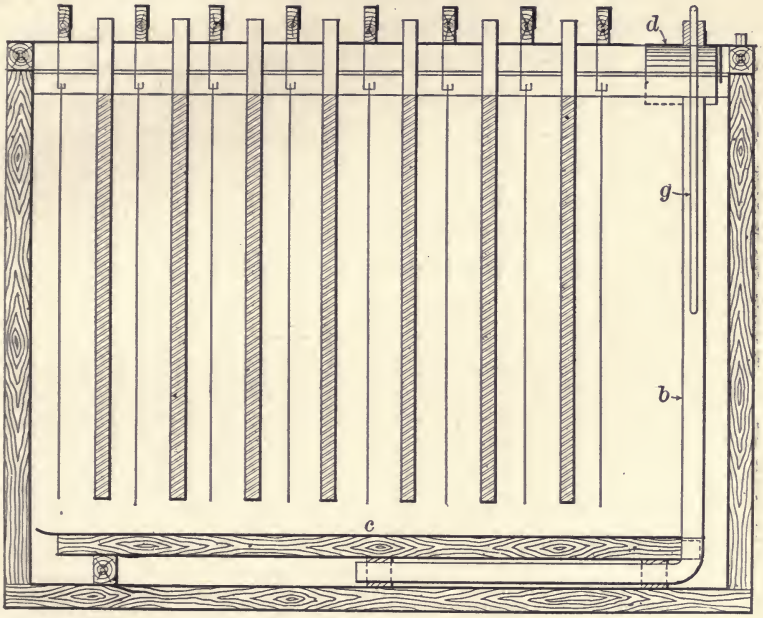

FIG. 67.—Siemens-Borchers Copper-refining Tank.

liquid by ejecting a lead cover, *d*, with an opening toward the electrodes, must be placed over the pipe *b*. *c* = collecting tray for anode residues and slimes.

The above apparatus obviates the necessity of having the electrode flow from one tank to the next of a long series. The impurities of one tank are not carried through the whole line. Each bath works independently of the rest. There should be no occasion for leakage of electric current

and wasteful overflows of liquid, as in the old system. The electrolyte remains in the bath from the start up to the time when it must be discarded. The liquid, it is claimed, will always be found quite clear, a very important point in hunting up the cause for any troubles in the line. One pipe line only is required to fill and to empty the tanks by air pressure and suction. And last, but not least, the current density may be raised to three or four times that heretofore used in Europe. This means nothing less than the possibility of turning out three or four times as much copper as by the old method; or a given amount of metal will require only one-third or one-fourth of the floor space formerly needed.

The economy of operating a refinery with tanks supplied with the above apparatus, as compared with the old style of tanks, will appear from the following table furnished by Siemens & Halske for technical conditions as they exist in Germany:

Daily Operating Cost with a Production of 1 Ton per Diem.	Formerly: Current Density 3 Amperes per sq. ft.	At Present: Current Density 10 Amperes per sq. ft.
Cost of power (1 horse-power hour @ 5 pfennig = 1.2 cts.)	Mark: 17.00	Mark: 30.00
Wages	" 30.00	" 15.00
Interest on copper in treatment (5%)	" 15.60	" 4.80
Amortization of the electrical installation (10%)	" 8.30	" 4.15
Cost of heating the electrolyte (250 kg. coal)	"	" 5.00
Cost of regenerating the solution	" 4.00	"
	Mark: 74.90 =$17.60	Mark: 58.95 =$13.85

5. Schladern Electrolytic Works.

The Elmore Metall-Actiengesellschaft, whose head office is in London, is operating a modified Elmore process at Schladern a. d. Sieg, near Cologne, Germany. The process and equipment employed being identical, it is claimed,

with that of the Leeds Copper Works, excepting in size, I must refer the reader to the description of the latter plant on pages 116 to 123 of this monograph. About 1000 H.P. are employed in these works and somewhat better results have been secured, it is claimed, than in England.

6. Niedermarsberg Refinery.

This refinery, also known as the Stadtberger Huette, at Niedermarsberg, near Cologne, is operated in connection with a leaching plant. Carbonate ores containing about 2% Cu are leached with a solution of hydrochloric acid and salt and with such iron chloride solutions as are obtained in a subsequent stage of the extraction process. In this way about 1.5% Cu is recovered, while the greater part of the remaining 0.5% Cu in the ore is extracted from the dump of the leached ore as follows: The floor of the dump pile is located on a level above that of the leaching plant, so that the cupriferous solutions resulting from the action of the residual chloride solutions in the leached ore, together with that of the oxygen and moisture of the atmosphere on the ore, may be washed down by rain-water into ditches and their copper contents precipitated therein by scrap iron. In this way a very high extraction of the copper contents of the ore is effected and nearly 900 tons of metallic copper are recovered annually.

The precipitation of the copper is carried out in such a way as to first throw down practically all of the precious metals in the solution, together with about 37% of its copper contents only, thus obtaining a product which is sent to the electrolytic refinery (arranged on the old Siemens pattern) for separation, while the greater portion of the copper in the cupriferous solutions is thrown down by means of scrap iron free from precious metals, and therefore merely requires furnace refining to put it into marketable shape.

The total copper output of the Stadtberger Huette is nearly 900 tons annually, of which about 330 tons represents electrolytic copper.

7. Altenau Electrolytic Works.

This plant, operated by the Koenigliches Huettenamt Altenau im Oberharz, receives power furnished by a Briegleb Hausen turbine, delivering between 17 and 28 H.P., according to the available quantity of water. In reserve is kept a 20 H.P. horizontal condensing engine, working with 8 atmospheres boiler pressure.

The daily production of electrolytic copper is at present from 0.8 to 1 ton.

The anode slimes are mixed with lime, pressed into bricks, dried, and smelted in a blast-furnace with a lead charge and basic slags, and the argentiferous lead bullion thereby obtained is cupelled and parted in the ordinary way.

8. Burbach Refinery.

This plant, belonging to Mr. C. Schreiber, of Burbach Siegen, is a very small one, operated with but 15 H.P. and producing not over 0.2 ton of electrolytic copper daily by the ordinary multiple process.

9. Papenburg Electrolytic Works.

These works, belonging to the Allgemeine Elektro-Metallurgische Gesellschaft, at Papenburg an der Ems, are said to be producing a small output of copper and nickel, according to a modified Hoepfner process, using a chloride solution. It is stated that the capacity for which the works were designed is as much as 1 ton of refined copper daily, although the actual output is only a fraction of a ton, and that the following process is in use: The ores and matte

received at the works are leached with a cupric chloride solution, so as to dissolve their copper, nickel, and silver contents and simultaneously reduce the cupric salt to the cuprous state. After purification and being freed from silver, the solution is passed into electrolytic cells with carbon anodes and copper cathodes. Chlorine is liberated at the anodes, and the cupric solution remaining after electrolysis is withdrawn and reused in leaching a fresh charge of ore or matte until it is found desirable to recover the nickel in the solution.

Very recent reports indicate that the Papenburg concern has not achieved as successful results as were expected, and that the entire plant is therefore being remodeled.

D. AUSTRIA-HUNGARY.

By VICTOR ENGELHARDT.

1. Witkowitz Electrolytic Refinery.

This plant, owned by the Bergbau u. Eisenhuettengewerkschaft at Witkowitz, Moravia, was started eighteen years ago in connection with the treatment of pyrites cinders from the acid works, which were then and are now used in part in making pig iron, owing to the difficulty of obtaining iron ores from other sources low enough in phosphorus to fall within the Bessemer limit for steel.

The aforesaid pyrites cinders contain, besides a few tenths of a per cent. of copper, larger proportions of residual sulphur. Both of these elements are converted into soluble compounds by giving the cinders a chloridizing roast and then leaching them, whereby a residue is obtained which is used in making iron. The copper in the leach liquor is precipitated with iron as cement-copper finally, which product contains Cu, Fe, Pb, As, Ag, and traces of Au, and is refined electrolytically. Electrolytic refining

was adopted for the reasons, 1, that it enabled the separation of the copper from the other metals to be effected easily and completely; 2, because the copper was obtained as a readily salable product, and 3, because a large difference in prices existed between electrolytic and fire-refined copper at the time the works were built.

The cement-copper is first partially refined by a reducing smelting process and then cast into anodes. The original cathodes are thin sheets of copper suspended between anodes in the electrolyte, which contains 35 to 40 g. Cu as copper sulphate and 50 to 55 g. SO_3 per liter of solution.

The composition of the anodes is as follows: 94–98% Cu, 0.4–1% Ag, 0.2–1% O, 0.02–0.7% Fe, 0.8% As, 0.05% Pb, and traces of S, Ni, Co, and Au.

At the commencement of operations, in 1884, the plant contained two rows of 6 tanks each, with 8 anodes and 7 cathodes to a tank. A Siemens machine of 240 amperes and 11 volts furnished the required current, which was employed at a current density of only 25 amperes per square meter, equivalent to 2.5 amperes per square foot of cathode surface.

At present there are 72 tanks in use, the adjoining tanks of a pair being separated by a partition which allows free communication of their solutions below. A tank holds but 4 anodes and 3 cathodes.

The current is furnished by two Siemens & Halske generators, one cF7 of 240 amperes and 11 volts, and the other cH7 of 300 amperes and 17 volts. An average current of 290 amperes is used, and a current density of 66 amperes per square meter of surface, i.e., 6.6 amperes per square foot.

The average annual output of the plant is 92.5 metric tons of copper, analyzing 99.99% Cu. It is reported that in one year 2231 metric cwt. of electrolytic copper were

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produced from 3260 metric cwt. of cement-copper, obtained from 470,600 metric cwt. of pyrites cinders.

2. Brixlegg Electrolytic Refinery.

This plant at Brixlegg, Tyrol, belongs to the K. K. Berg u. Huettenverwaltung, and contains 60 depositing tanks, 12 electrolytic receiving tanks, 6 membrane pumps for raising the circulating solution, 2 ampere-meters, 3 volt-meters, 2 torsion-galvanometers, and 2 Siemens & Halske generators, type cH_7, with air commutators, and delivering a current of 240 amperes at 20 volts potential.

In 1884 the government installed the first plant, consisting of 1 generator and 2 rows of 10 tanks each, arranged in cascades, and with a receiving tank and pump for each row. To this plant additions were made from time to time, so that at present there are two dynamos in use, one serving 4 rows of 10 tanks each and the other 2 rows.

The material treated in the electrolytic refinery consists of gold- and silver-bearing partly refined black copper containing only 90% Cu and 1% Ag, besides 0.005% Au. The electrolyte is an acid solution of bluestone. The electrolytic cathodes produced are remelted in a refining furnace and cast into cakes for rolling into sheet, and the silver slimes are refined by cupellation with lead on a cupel hearth.

The average annual output of the refinery amounts to 45 to 47.5 metric tons of copper.

E. France.

1. Dives Electrolytic Works.

These works are operated by the Société d'Electro-Metallurgie de Dives, Paris, which is allied to the Leeds Copper Works, Ltd., and is using a modified Elmore

process of depositing copper for tubes, etc., rather than a refining process proper.

The plant, located at Dives, Normandy, has been running for some years past and constituted the pattern after which the Leeds Copper Works have been built and equipped. The reader is, therefore, referred to the detailed description of that plant on pages 116 to 123.

2. Biache St. Vaast Electrolytic Works.

These works, belonging to the Société Anonyme des Fonderies et Laminoirs de Biache St. Vaast (formerly Eschger, Chesquière et Cie), with offices in Paris, in 1895 had an estimated output of about 780 tons of electrolytic copper. The company at present declines to give out any information.

Dr. C. Schnabel's table, referred to above, shows that with each 8-H.P. Gramme dynamo, delivering a current of 700 amperes at 4 volts tension to 20 tanks, the Biache refinery at Pas de Calais deposits nearly 882 lb. of copper in 24 hours. The effective cathode area of each tank is a little over 227 sq. ft., a current density of about 3 amperes per square foot is employed and about 4.6 lb. of refined copper are deposited for each horse-power hour.

The anode slimes are reduced in a blast-furnace with litharge to a copper-lead alloy, and the latter is then cupelled with argentiferous lead.

3. Pont de Cheruy Refinery.

This plant, also known as the Grammont Affinerie, located at Pont de Cheruy, in 1895 had an annual output, it is claimed, of about 400 tons of electrolytic copper. The tanks are connected in series and the electrodes in parallel.

The anode residue, containing, say, 25% Cu and 1% to 6% Ag, is treated, according to Thofehrn, by exposing it

to the atmosphere and then melting it down to get rid of the greater part of its metallic oxides other than those of copper and silver. For this purpose a magnesia brick-lined refining furnace is used. Finally an alloy containing as much as 80% Cu and 15% Ag is produced, which is cast into plates and subjected to electrolysis in special vats, in which the main refinery current and electrolyte is caused to circulate. Merchantable copper is thus obtained and slimes rich enough in silver for final acid treatment in the usual way.

4. Marseilles Electrolytic Refinery.

This plant, belonging to Hilarion, Roux et Cie, Marseilles, according to Schnabel, in 1898 produced about 551 lb. of copper daily with a 5-H.P. Gramme dynamo, delivering 300 amperes at 8 volts tension to 40 tanks. The effective cathode area of each tank is about 242 sq. ft., the current density employed about 1.24 amperes per sq. ft., and 4.59 lbs. of refined copper are deposited per hour for each horse-power used.

The Société de Cuivre de France's Refinery at Eguille, whose annual output in 1895 was reported at 1100 tons and whose general arrangement was planned by H. Thofehrn, is not now in operation.

F. Russia.

1. Kalakent Copper Works.

By Gustav Koelle.

These works (owned by the Hon. Carl H. von Siemens and the heirs of the late Privy Councillor Werner von Siemens) were established for the purpose of electrolytically refining crude copper and securing the contained precious metals, and are located at Kalakent, near the Kedabeg Copper Works, about 60 wersts or 40 miles southwest of

the city of Elisabethpol and 42 wersts or 28 miles from Dalliar Station on the Transcaucasian Railroad.

Originally the plant was intended to carry out experiments on a large scale for the direct electrolytic extraction of copper from ores, according to the well-known Siemens and Halske sulphate process, but it was remodelled, as far back as 1889, and operated, at first with 36 tanks, in pro-

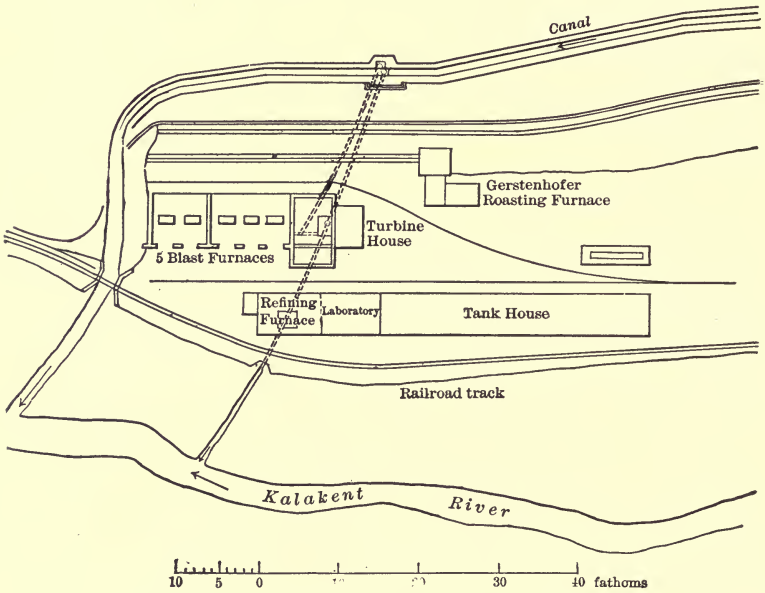

FIG. 68.—Ground Plan of Kalakent Works.

ducing merchantable copper from black copper anodes containing not over 90% Cu, and from which anode residues, running at most 2% in silver and gold, were secured. As the working up of these residues occasioned difficulty, and moreover, as the obtained electrolytic copper was of an uncertain quality, this non-paying procedure was given up, and in its stead the management substituted the refining of blister copper instead of black copper and increased the plant in size. As such the works were operated

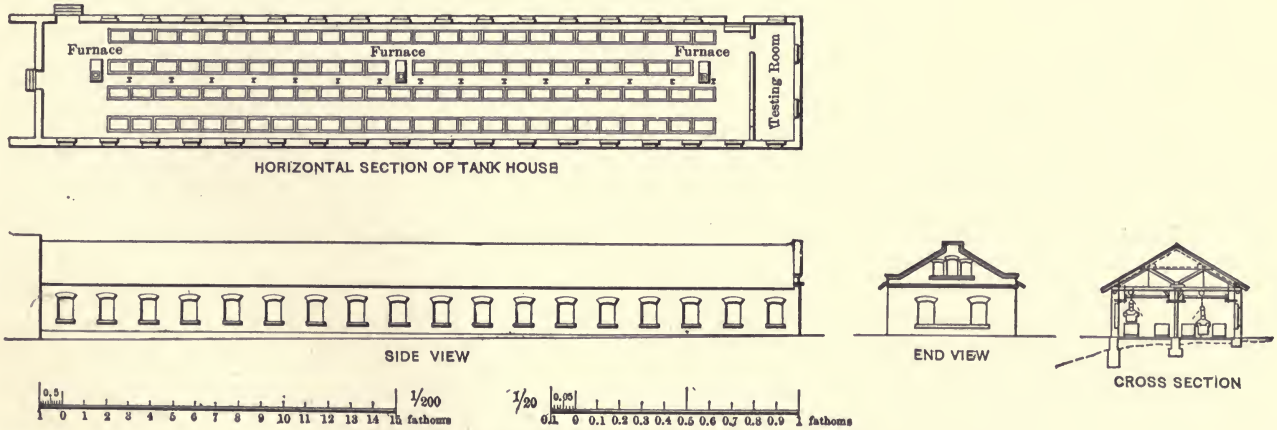
Furnace
Furnace
Furnace
Testing Room
HORIZONTAL SECTION OF TANK HOUSE
SIDE VIEW
END VIEW
CROSS SECTION
1/200
1 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 fathoms
1/20
0.1 0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1 fathoms

FIG. 69.—Tank-house of the Kalakent Refinery.

continuously from 1893 up to 1900, since which time they have been closed down, because it was believed that no profit could be realized by them on account of the following facts: 1. The small percentage of precious metals (on an average only 0.06%), and of which the gold amounts to but $\frac{1}{15}$ to $\frac{1}{17}$ part, in the Kedabeg copper; 2, the small margin of profit between electrolytic and fire-refined copper, which was reduced to only 25 kopeks per pud, i.e., 0.3c. per lb.; and finally, the abnormally high local prices of certain necessary supplies, such as sulphuric acid, which cost 1.90 rubel per pud, i.e., 2.7c. per lb. The electrolytic copper-refining industry in Kalakent is therefore dormant at the present time.

The Kalakent works embraced 102 electrolytic tanks, and were designed for an annual output of 25,000 pud, or 450 tons, of fine copper.

Current was obtained from Siemens & Halske shunt-wound dynamos furnishing 700 amperes at 35 volts, and of which only one machine was kept in operation at a time.

The tanks were arranged in four rows, all placed on the same level. The arrangement of the tanks, as indicated in Figs. 70 and 71, differed from the ordinary and usual disposition, particularly with respect to the system of circulating and renewing the electrolyte. It permitted of making each tank an independent unit, if desired, by the employment of Siemens air-lifts, two of which were placed in each tank to circulate the electrolyte. This made possible the operation of the tanks individually or grouped in any desired way and number, facilitated the control of each tank, and permitted the easy renewal or restandardizing sectionally of impure or abnormal solutions, which is a very important consideration.

The tanks were built of pine, 2 m. or 6.6 ft. long, 1.15 m. or 3.8 ft. high, and 0.96 m. or 3.1 ft. wide, inside measurements, and were lined with jute linen soaked in asphalt,

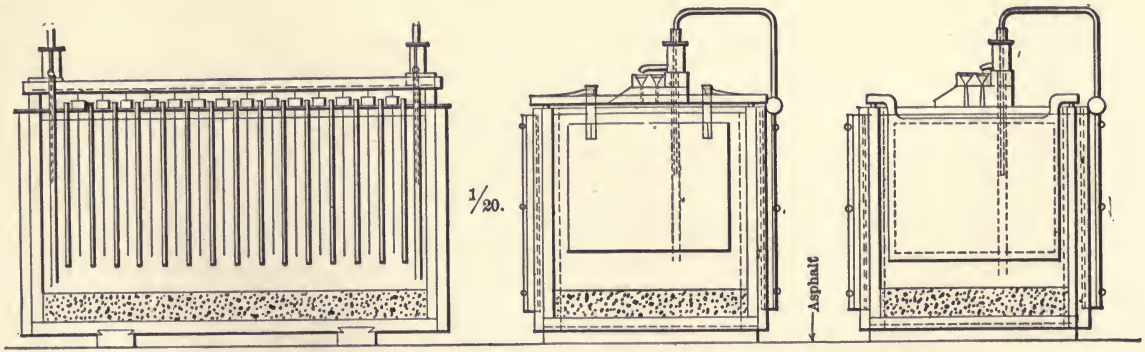

FIG. 70.—Vertical Sections of Electrolytic Tank with 15 Anodes and 14 Cathodes.

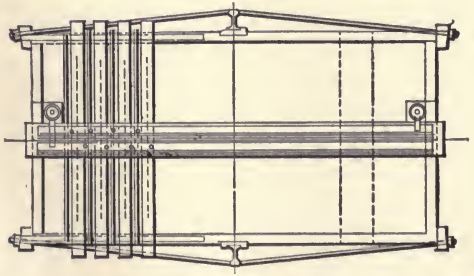

FIG. 71.—Horizontal Section of Electrolytic Tank.

a method not to be specially recommended, but which was in this case employed because the price of lead in Russia is exceptionally high. It possesses this disadvantage, that the jute lining is apt to be ripped open by falling sharp-edged pieces of copper, which is, of course, partly provided against by placing wooden boards on the bottoms of the tanks. Another difficulty arises from the quality and treatment of the calking material, in this case Welsh asphalt and asphalt varnish, for if this material is not boiled sufficiently long before using, it will be acted upon by the free acid in the tank and cause an evolution of oxygen and carbonic acid, which in turn may injuriously oxidize the cathode copper. Its advantage over lead lining lies only in its cheapness, and possibly also in the lesser liability therewith of having short circuits.

The conductors, electrolytic copper bars placed lengthwise of the tanks, were 500 sq. mm. or 1.7 sq. in. in cross-section, or not quite as large in sectional area as the main conductors. Each tank contained 15 anodes and 14 cathode plates, so that it had an anode at each end. The electrodes were arranged, as usual, in parallel, and the tanks in series circuit. The electrodes were spaced about 5 to 6 cm. or about 2 in. apart. It was observed that if this distance was decreased there arose danger of short-circuiting, and if increased, the voltage became too great for economy.

The effective anode area per tank was 20 sq. meters or 200 sq. ft.; of the cathodes, 19 sq. meters or about 190 sq. ft.

Every anode, cast from ordinary blister copper, weighed between 8 and 10 pud., i.e., about 248 to 360 lb., and was about 90 cm. or about 3 ft. long, 86 cm. or 2.8 ft. wide, and 2 cm. to 2.5 cm. or .8 in. to 1 in. in thickness. Serving as cathodes to receive the commercially deposited copper in the tanks were employed sheets of electrolytic copper 2 mm. or .08 in. thick, obtained in the usual

way in special cathode tanks by electro-deposition on plates of ordinary rolled copper smeared with oil and graphite, and whose edges were insulated with paraffine. Before using they were first freed from adhering oil, etc., by heating,

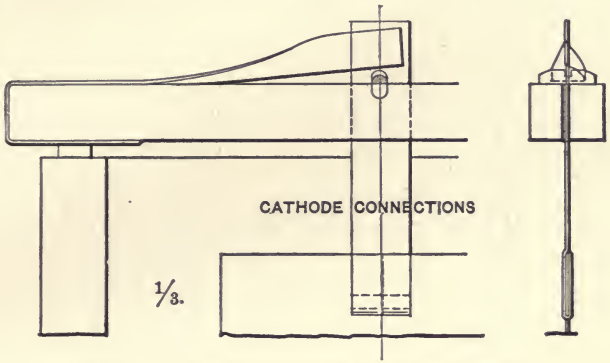

FIG. 72.—Details of Cathode Connections.

and were then supplied with the necessary suspending and conducting strips.

To accomplish the circulation of the electrolyte, which had to be carried on with the greatest energy to secure good, even copper deposits, each tank was supplied with two geyser pumps (air-lifts) whose construction is clearly indicated in Fig. 73. By means of air pressure admitted through the narrow pipe, shown in the figure, continuously under a pressure of 70 mm. or 2.8 in. mercury column, the solution from near the bottom of the tank is lifted up through the larger pipe and overflows into a distributing trough above the tank to mix with or renew the layer of electrolyte near the top. In this way about 800 liters of solution are circulated per tank and hour.

Current densities of 25 amperes up to a maximum of 30 amperes per square meter or 3 amperes per square foot of cathode area were employed; an increase of the amperage above this maximum resulted in brittleness of the deposited copper unless the acidity of the electrolyte was

increased simultaneously. A remarkably high average current efficiency, 99%, was obtained in the Kalakent works. In order to secure a very good deposit of fine

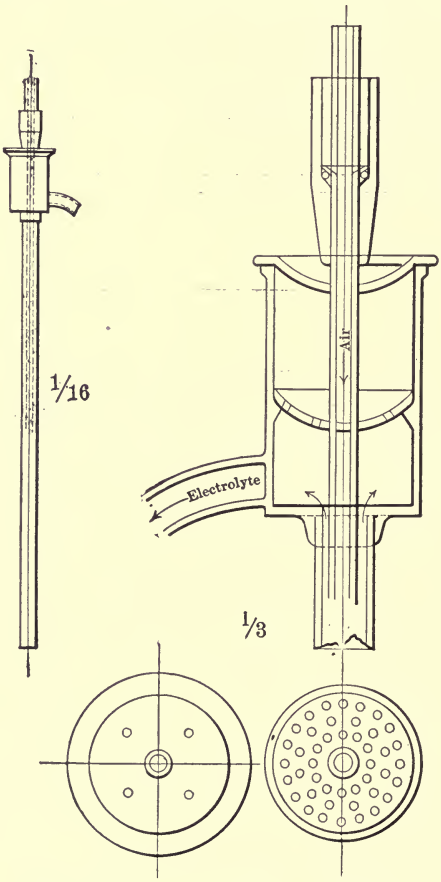

FIG. 73.—Circulation Pump (Air-lift).

copper, it was found that the acidity had to be kept at not less than 70, and generally between 75 and 85 grams of free sulphuric acid per liter, and that at least 36 grams of copper had to be present in a liter of solution.

The composition of the better brands of fire-refined

blister copper used as anodes was as follows: 99.57% Cu, 0.06% to 0.08% Ag+Au, 0.027% Pb, 0.038% As, 0.060% Sb, 0.031% Ni+Co, 0.009% Fe, and traces of bismuth.

Notwithstanding the comparatively low contents in impurities of the material treated, these accumulated in the course of time and then necessitated purification of the electrolyte to prevent deterioration of the copper deposits. Especially dangerous was the concentration in the solution of those oxides easily soluble in dilute acid, such as iron and arsenic (arsenious acid) and also of bismuth and antimony compounds. As long as a sufficient excess of copper over these other metals was present in the electrolyte, and the total amount of these impurities did not exceed a certain maximum, indicated by the peculiar appearance of the cathode surfaces, no fault could be found with the deposited copper. The presence of an abundance of free sulphuric acid in the bath prevented the precipitation of the oxides of copper at the negative poles.

When the impurities in the electrolyte had accumulated to such an extent as to endanger the quality of the electrolytic copper, the foul solutions were withdrawn from the individual tanks or tank groups and regenerated, this regeneration being accomplished with considerable difficulty at first, but finally it was done advantageously as follows:

The foul solutions were heated and passed over dead-roasted matte fines heaped in loose-bottomed trays arranged in series in upright rows. By this method all the sulphuric acid in the solution, down to about 2 grams per 100 cu. cm., was neutralized and combined with copper and iron. The solution was then allowed to trickle through heaps of roasted low-grade copper ores, which resulted in the almost complete neutralization of its acid contents. It was now diluted with wash waters down to 10° to 12° B. and heated,

to free the solution from iron, arsenic, tin, and bismuth, in lead pans, which were provided with an appliance for injecting compressed air into the solution. Anode scrap was suspended in the pans so as to neutralize any remaining portions of acid, and to take up any new acid set free through separation of iron hydrates, and thereby form copper sulphate. By blowing compressed air into the solution heated to about 50° C., the copper in the anode residues or scrap was quickly dissolved, and the separation of the iron, arsenic, antimony, tin, and bismuth, which occurred when the solution had been nearly or completely neutralized, accomplished. The solution was then concentrated up to 14° to 15° B. and clarified in special reservoirs. It now contained 3.5 to 4 grams copper per 100 cu. cm., and of impurities only 0.5 to 1 gram iron, besides traces of zinc, nickel, and cobalt, and was therefore pure enough for reuse as electrolyte. The excess of purified electrolyte which gradually accumulated with this method of regeneration was eventually withdrawn from the circulating system and worked up into bluestone.

The electrolytic copper put on the market possessed a purity of at least 99.9% by analysis and averaged 99.93% copper. It was sold in the shape of plates weighing 8 to 9 pud (i.e. 288 to 324 lb.).

The silver mud or anode slimes obtained as a by-product in refining the anode copper were not worked up into gold and silver bullion, but were merely enriched and shipped to Germany and sold, this being considered a more profitable procedure than their treatment in Russia.

The enrichment of the slimes, consisting chiefly in the partial removal of the contained copper, was carried out as follows:

After removing any adhering solution from the mud by washing with water and decantation, the slimes were leached with a quantity of impure acid electrolytic solu-

tion, heated to from 50° to 55° C., so as to diminish their copper contents from 35% or 40% down to 10% or 15% Cu. The leached slimes, which were then sold, averaged 25% to 30% in precious metals, of which gold constituted the fourteenth to seventeenth part. Practically all of this material was purchased by the North German Refinery in Hamburg.

2. Nikolajev Refinery.

This electrolytic plant at Nijni Novgorod, comprising 70 depositing tanks, a few years ago was producing at the rate of 15,000 puds of electrolytic copper per year, which equals about 0.75 ton per day. A current density of 45 amperes per square meter of cathode surface, equivalent to 4.5 amperes per square foot, is reported as being employed in refining the crude copper treated.

CHAPTER III.

COST ESTIMATES OF AN AMERICAN COPPER AND NICKEL REFINERY, WITH GENERAL PLAN AND DETAIL DRAWINGS.

Description and Specifications.—The following preliminary estimates and plans refer to proposed custom refining works to be located at Sault Ste. Marie, Michigan, where cheap water-power is available, and arranged in accordance with my improved copper-nickel refining process and plant. I designed the works for a daily productive capacity of 75 tons of fine copper, 7.5 tons of fine nickel, and for refining the precious metals contained in the material to be treated.

The chief data for the estimates were obtained by securing bids for the items specified, and were carefully compiled.

The works are designed especially for treating anodes of crude nickeliferous copper, averaging, say, 88% Cu, 8.8% Ni, and 22.13 oz. of Ag per ton, valued at approximately 11.5c. and 15c. per lb. for the contained copper and nickel respectively, and not exceeding 50c. per oz. for the contained silver, or a total of about $239.87 per ton.

These nickeliferous copper anodes may be secured by bessemerizing charges of Sudbury copper-nickel matte added to common argentiferous copper matte and pouring the converted metal into the desired shape, or by adding Sudbury matte to argentiferous copper concentrates, such as silver-bearing "mineral" from the Quincy, Isle Royale, Osceola, and other Upper Peninsula stamp-mills, to bring

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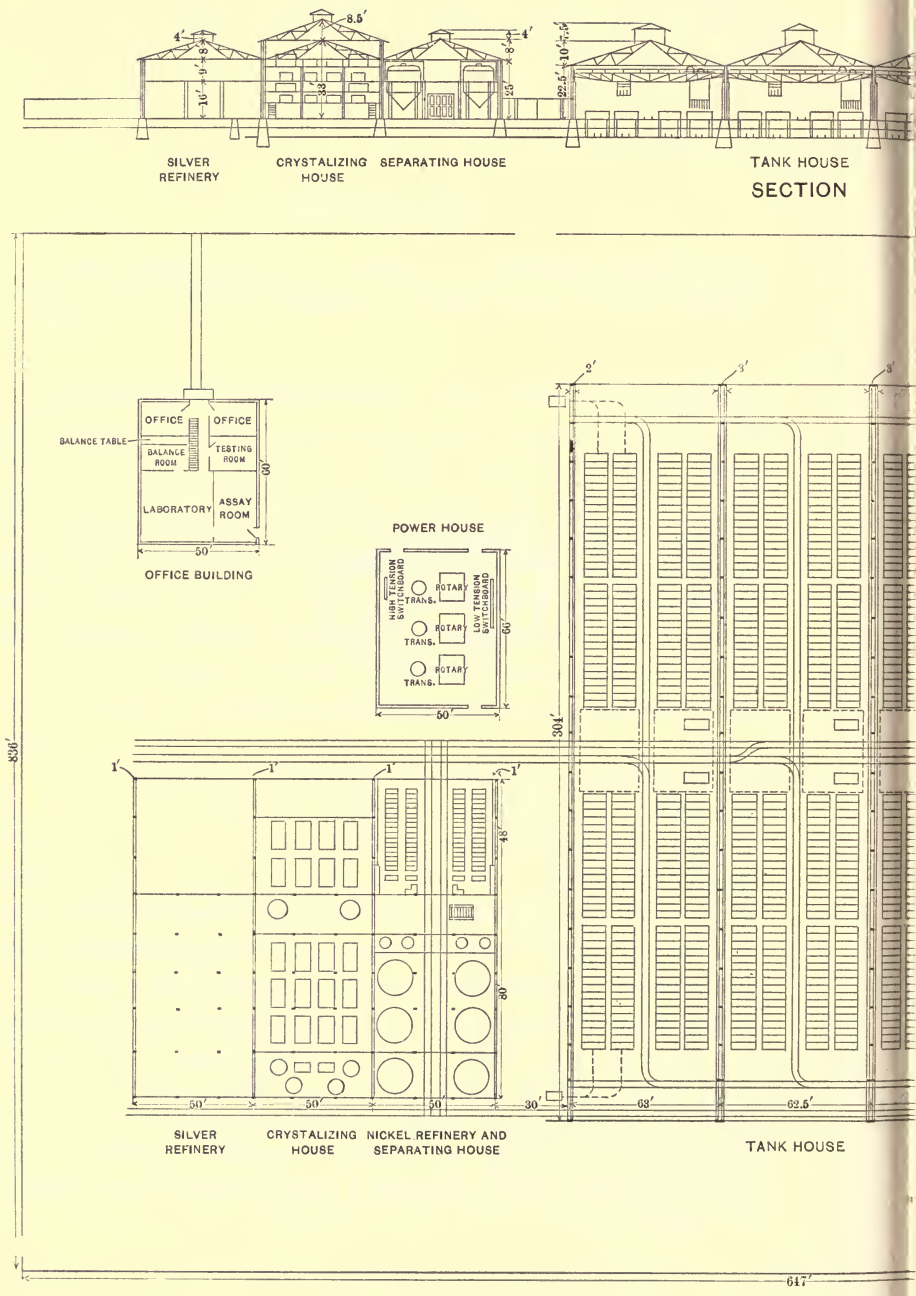
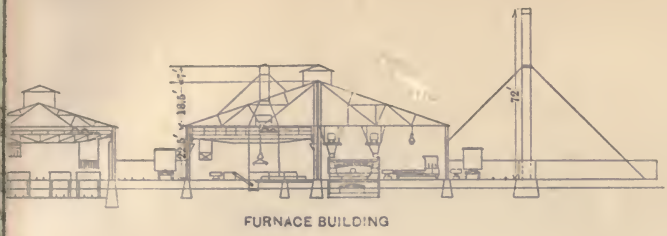
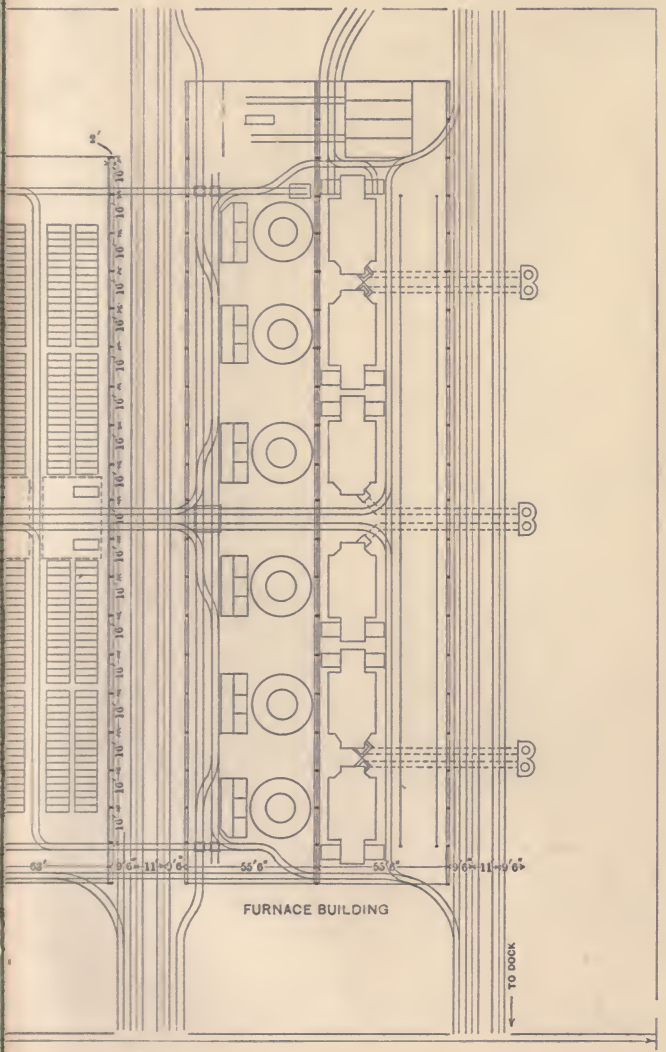


FIG. 74.—Plan, Elevation, and Section of





Proposed Copper and Nickel Refinery.

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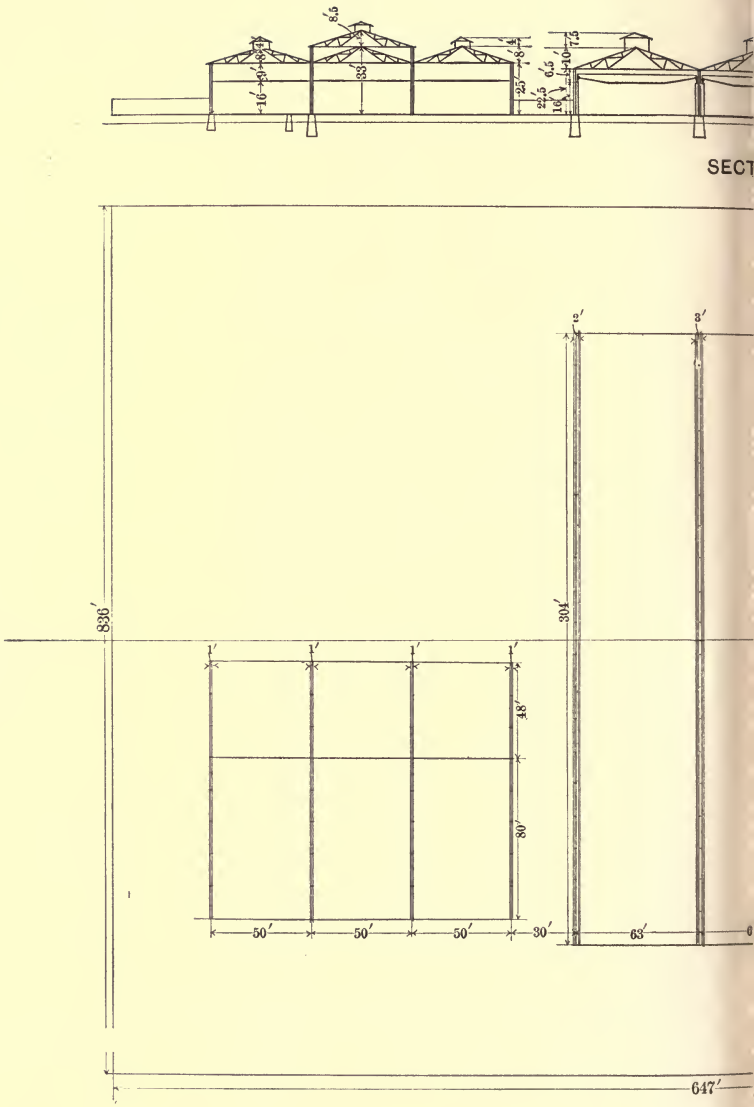
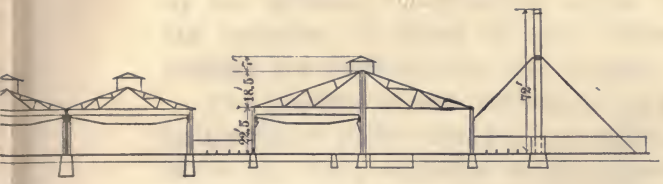


FIG. 75.—Plan and Sect on of Proposed



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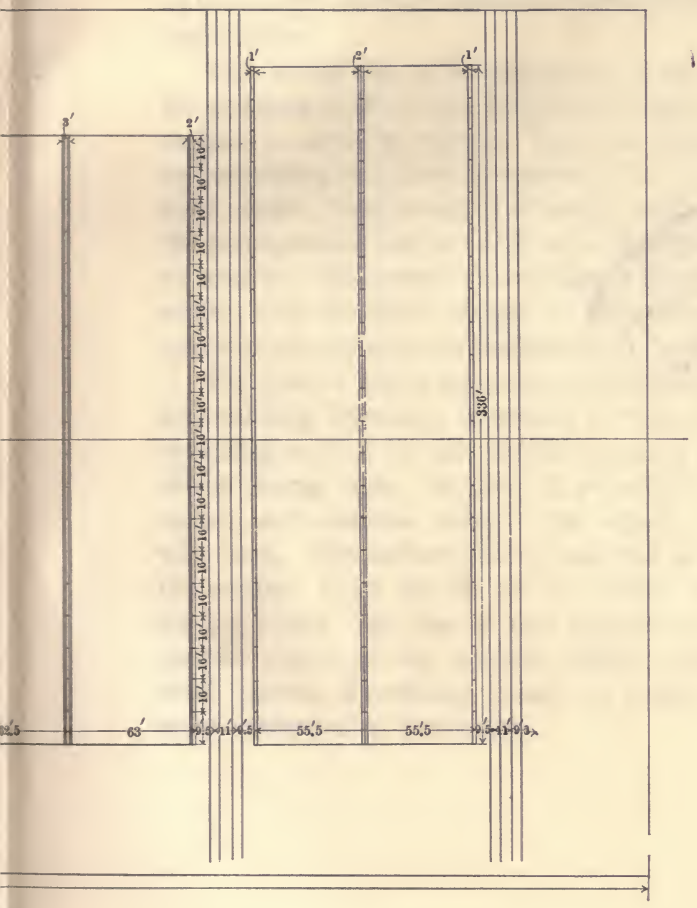

LAN

d Copper and Nickel Refinery.

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up the quantity of contained copper to nine or ten times the quantity of nickel present, refining this charge and pouring the finished alloy into anodes.

The required power, between 3400 and 4000 H.P., is to be furnished in the shape of a 3-phase alternating current of 10,300 volts, delivered to the high-tension switchboard of the refinery power-house, at a total yearly cost or price of $12.50 per metered electrical horse-power at the generating station.

The works are to be located on a site having facilities for shipping both by rail and water, flat in topography and at least 12 acres in extent. They are designed with a view to permitting of future extensions in at least two directions by a simple duplication of existing sections. Furthermore, the arrangement shown in the attached plan drawings, Figs. 74 and 75, will permit of erecting a limited section of the works, with whatever output of refined copper, nickel, and precious metals may be decided upon at first.

The cost of whatever coal may be used in the remelting and refining furnaces, in excess of that figured on in the operating cost of the electrolytic process, is considered as a direct charge upon the cost of manufacturing the copper, nickel, and precious metals into ingots, plates, slabs, and wire bars. The selling price is assumed at 12 ct. per lb. for the copper, 24 ct. per lb. for the nickel, and 50 ct. per oz. for the silver. In case of any increase or decrease in the quoted prices of the metals refined, after purchase, the total profits of refining would, of course, be proportionately increased or decreased.

SUMMARY.

Item.	Estimated Cost.	
Land	$1,200	
Grading land and building dock	32,000	
Tracks	5,040	
Office building	13,058	
Power-house	68,100	
Tank-house	161,610	
Furnace building	143,800	
Separating house and nickel refinery	34,540	
Crystallizing house	20,300	
Silver refinery	27,380	
Total cost of plant		$507,028
Permanent stock on hand		1,296,296
Incidentals, contingencies, and sinking fund		196,676
Permanent capital invested		$2,000,000
Value of total yearly output		$8,046,000
Yearly operating cost	$116,280	
Price of metal stock purchased annually	7,625,051	
Freight charges to market	148,600	
Total expenses		7,625,051
Total annual profit		420,949
Percentage of profit on capitalization		21.05%

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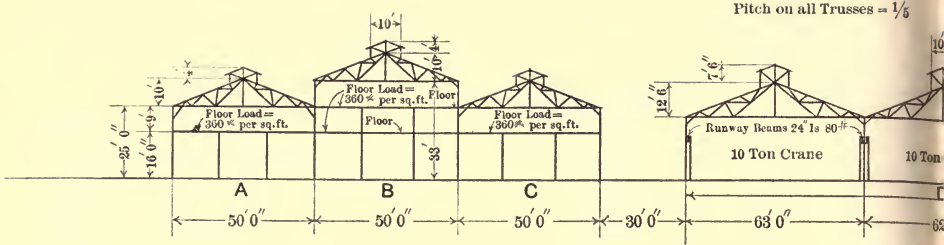
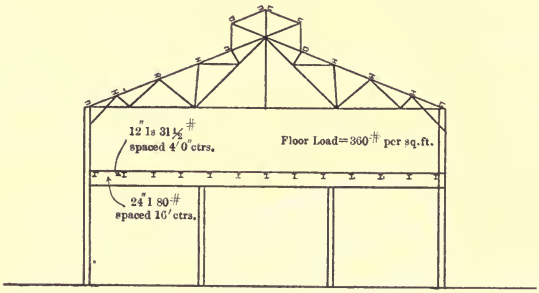
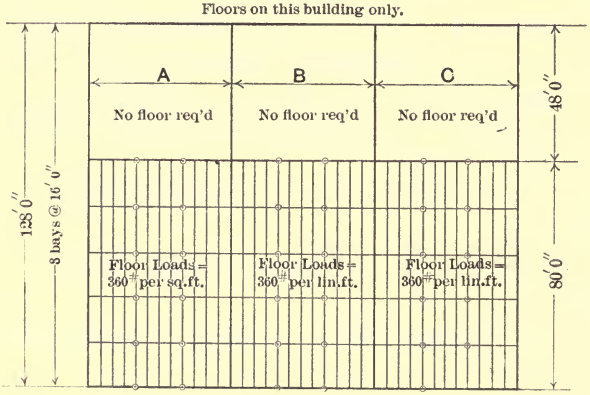


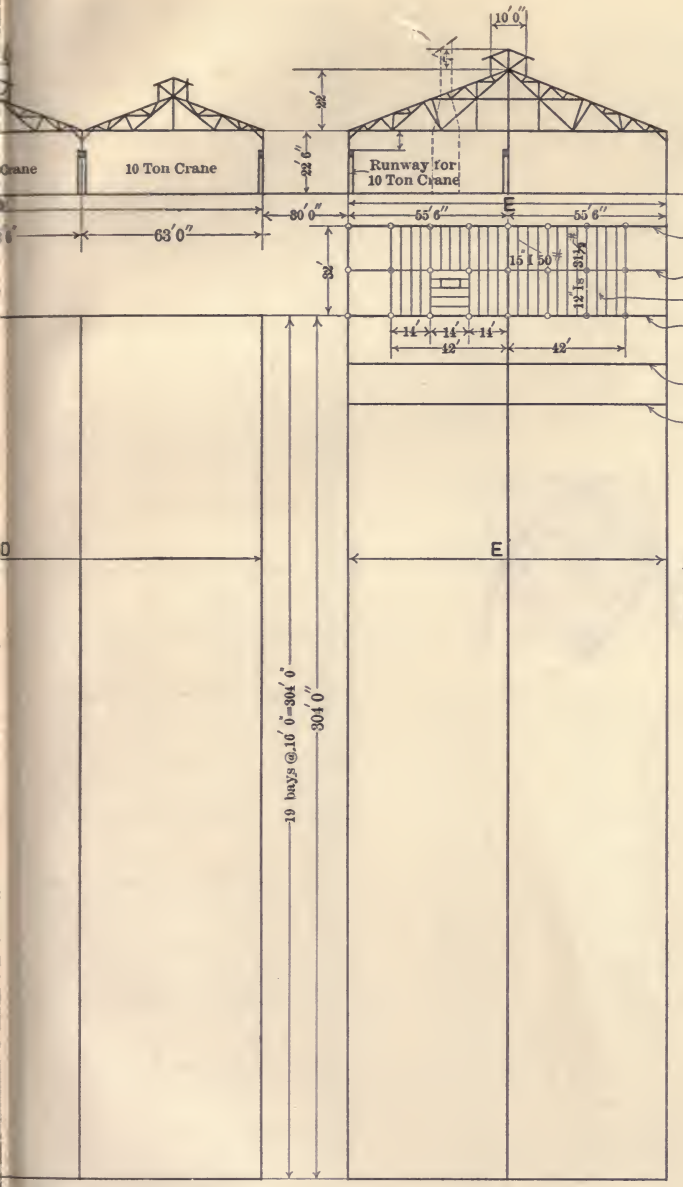


Steel Purlins on all Buildings, consisting of 5" I Beams 9¾# and 5" Channels 6½#.
Roof surfaces of Buildings A and E covered with corrugated iron, painted with 3 coats of Graphite Paint.
Sides and Ends of Building E covered with corrugated iron, painted with 3 coats of Graphite Paint, attached to Steel Girts.



Trusses supported on Columns throughout with curtain walls between Columns, exceptin and gable ends instead of brick curtain walls.

FIG. 76.—Diagram showing General Construction of Proposed Co



Building E, which has corrugated iron sidings

per and Nickel Refinery as submitted by the Canadian Bridge Co

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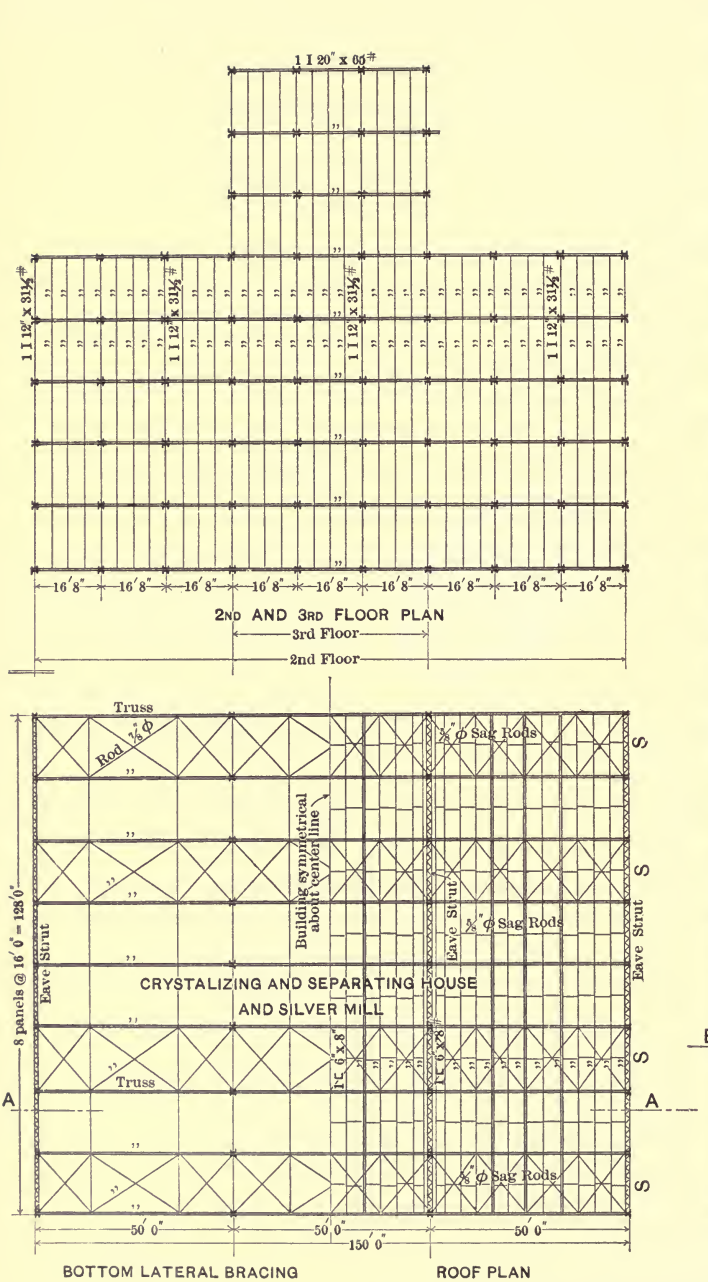
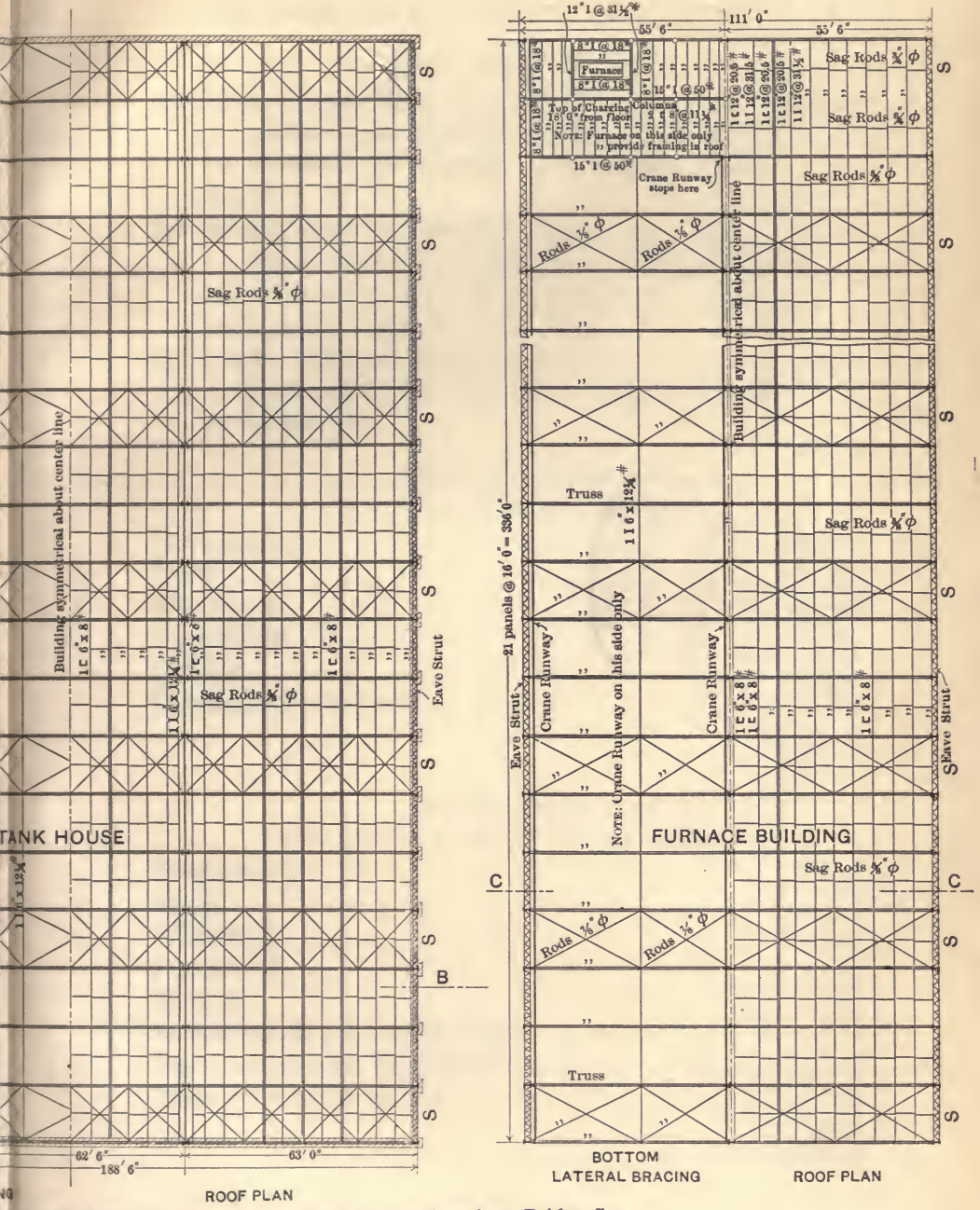


FIG. 77.—Floor and Roof Plan of Buildings for the Proposed Cop



per and Nickel Refinery. Submitted by the American Bridge Co.

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GENERAL EXPENDITURES.

(1) *Lana*, 12 acres @ $100 per acre..... $1,200
(Actual area required, allowing yard room for doubling the capacity of the plant, 836 × 647 ft.)

(2) *Grading land and building dock*..... 32,000
(Excavations to cost not exceeding $1.00 per cu. yd., and masonry $6.50 per cu. yd. Dock to be 400 ft. long by 20 ft. wide.)

(3) *Tracks*, 168 tons @ $30.00 per ton..... 5,040
(Industrial road, to be 30-in. gauge and rails 20 lb. per yd.)

OFFICE BUILDING.

(50 ft. by 60 ft., two stories.) See Fig. 74.

Foundations	$1,850
Brick	4,408
Woodwork	1,200
Furnishings	2,100
Fittings	1,500
Laboratory equipment	2,000
	$13,058

POWER-HOUSE.

(50 ft. by 66 ft., one story.) See Figs. 74 and 82.

Foundations	$2,000
Brick	4,800
Woodwork	1,200
Furnishings	2,100
Fittings	1,500
Switchboards and instruments	5,000
Three step-down transformers	12,000
Three rotary converters	39,500
	$68,100

TANK-HOUSE.

(189 ft. by 304 ft., one story.) See Figs. 74, 75, 77, 78, 79, 80, and 81.

Excavations and foundations	$7,500
Brick, 240 M. @ $25.00 per M., laid	6,000
Woodwork and furnishings, including 50 windows.	1,000
Fittings, including workbenches and 8 doors	1,000
Steel columns, trusses, and runways	60,000
Roofing, 580 sqs. @ $7.00 per sq.	4,060
Pumps and accessories	4,000
Air-compressor	1,700
Lead for lining tanks	21,700
Copper conductors and incidentals	6,000
Lead burning	4,050
Tanks (woodwork)	7,500
Lumber for floors and platforms	4,000
Brick foundations for tanks	7,000
Concrete flooring	2,500
Trolleys	2,000
Pipes for steam heating, etc.	1,500
Three 10-ton anode-handling cranes	20,100
	$161,610

FURNACE BUILDING.

(336 ft. by 111 ft., one and one-half story.) See Figs. 74, 76, 77, and 82.

Foundations	$7,500
Steel columns, trusses, and runways, corrugated iron roofs and sidings	45,000
One 10-ton traveling crane	3,600
Furnishings and fittings	1,000
Six 50-ton reverberating furnaces, with flues, complete	42,000
One 100-ton blast furnace and accessories	6,000
Six Walker casting-machines, with water-boshes, complete	27,000
One Wellman-Seaver charging machine	9,000
Six 72-foot stacks	2,700
	$143,800

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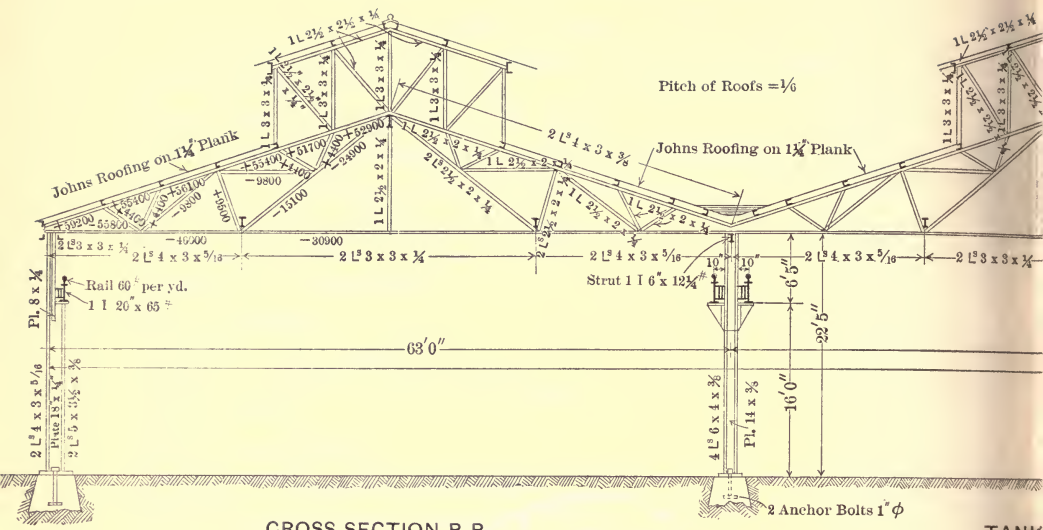


CROSS SECTION B-B

TANK

20 Corr. S
22 "
24 Sheet
22 "

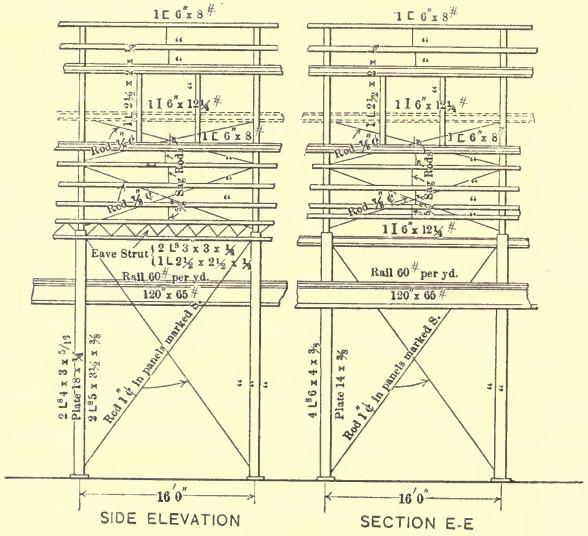
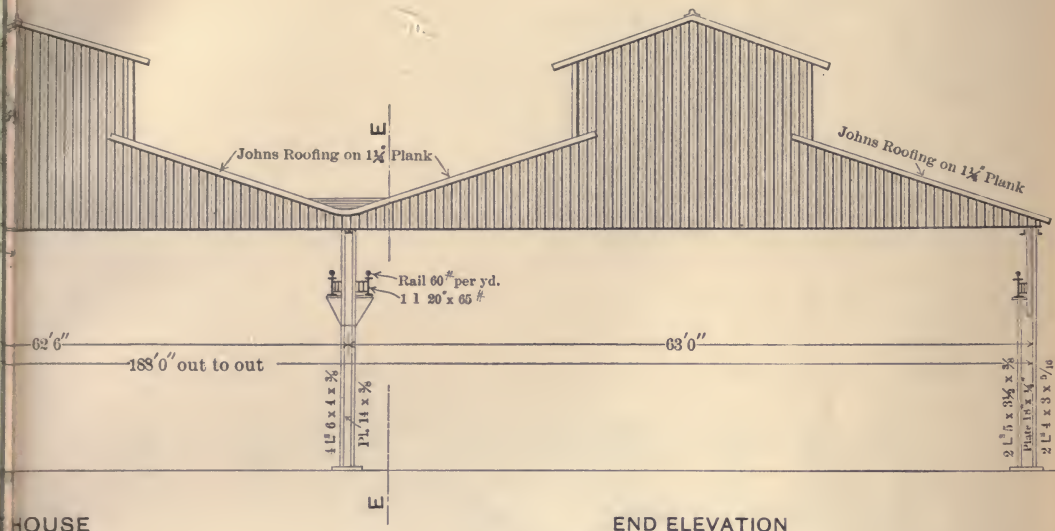


FIG. 78.—Drawing showing Steel


Johns Roofing on 1¼" Plank
Johns Roofing on 1¼" Plank
Rail 60# per yd.
1 1 20" x 65 #
62'6"
188'0" out to out
63'0"
4 L 6 x 4 x ⅜
PL 14 x ⅜
2 L 5 x 3½ x ⅜
Plate 18" x ¼"
2 L 4 x 3 x 9/16
E
E

HOUSE

END ELEVATION

tel on Roof.
" Gables.
Iron Ridge Caps.
" Gutters.

Construction of the Tank-house.

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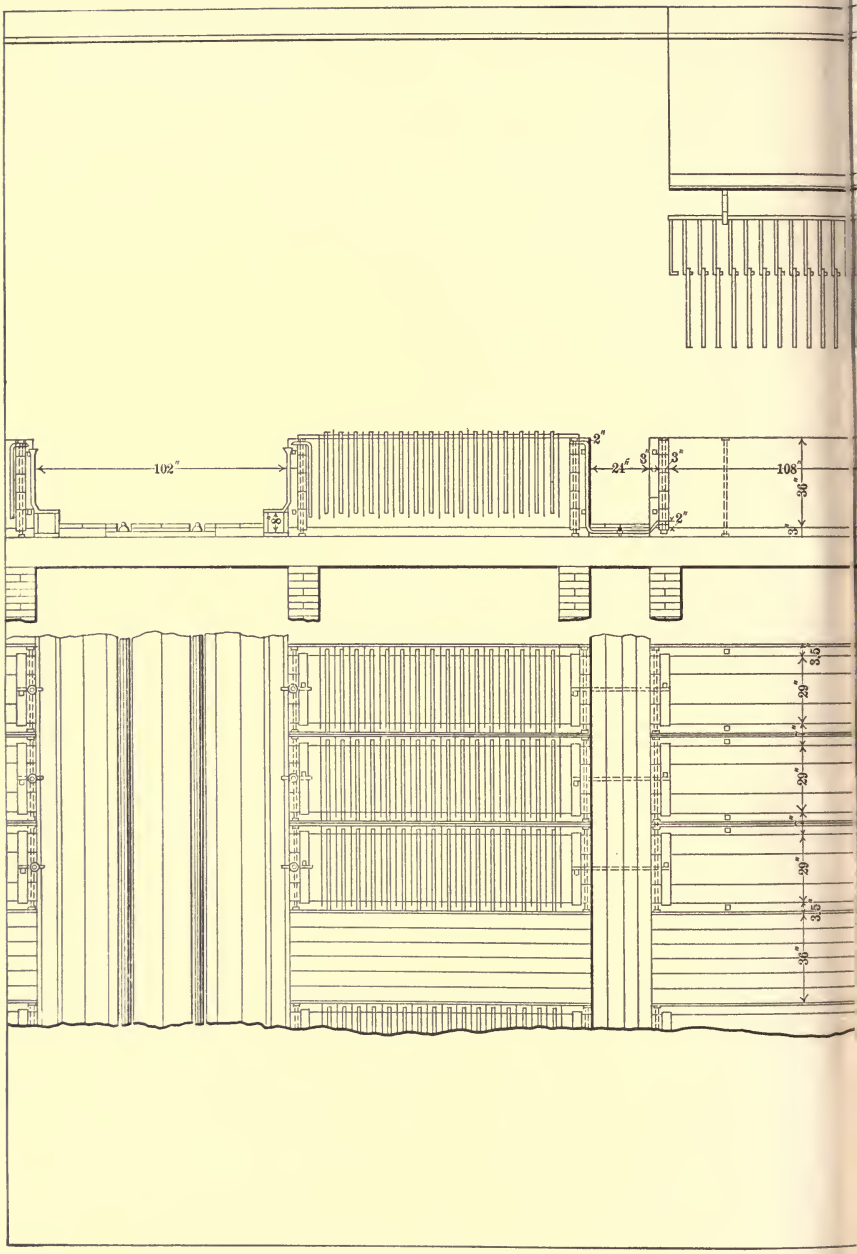
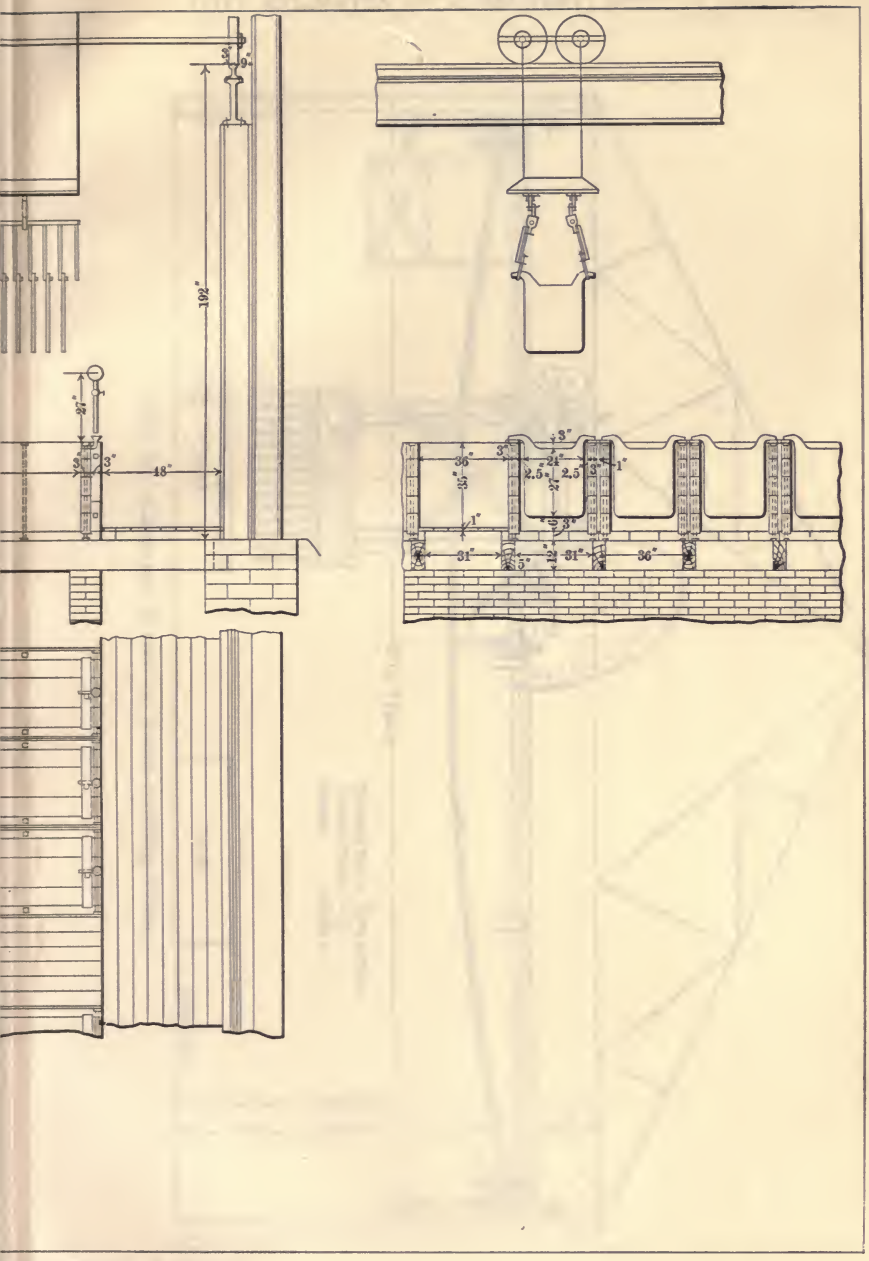


FIG. 79.—Sketch showing A



Arrangement of Tanks.

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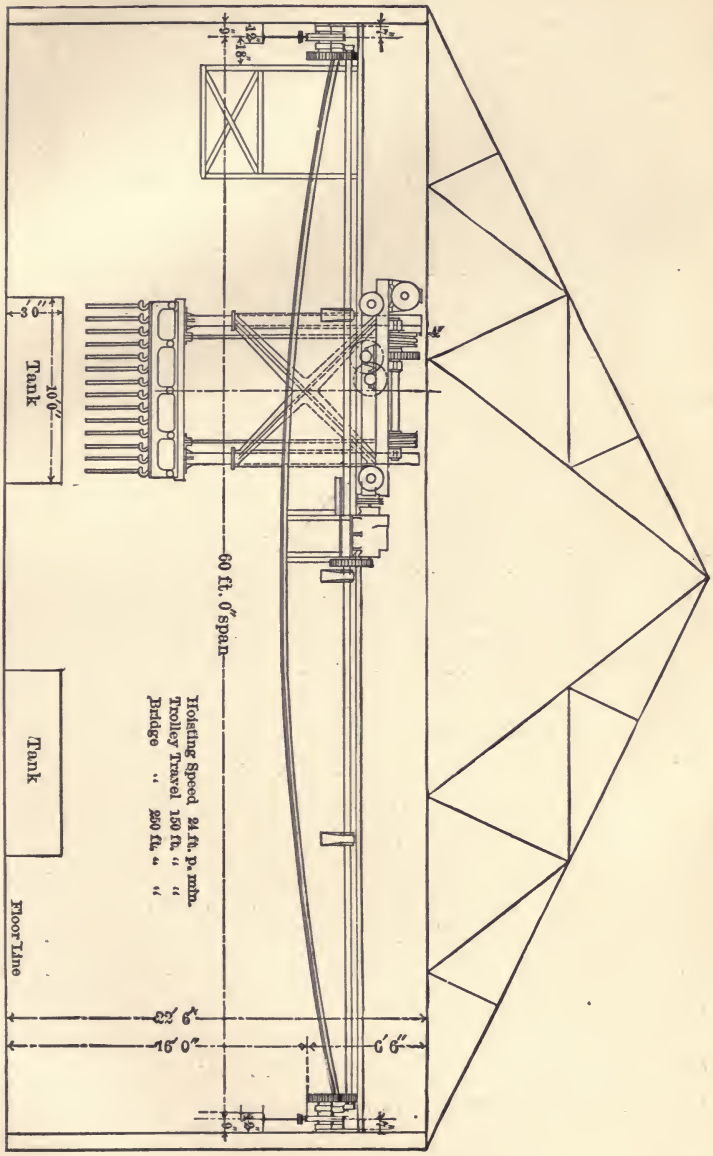

FIG. 80.—Clearance Sketch of Anode-handling Crane.

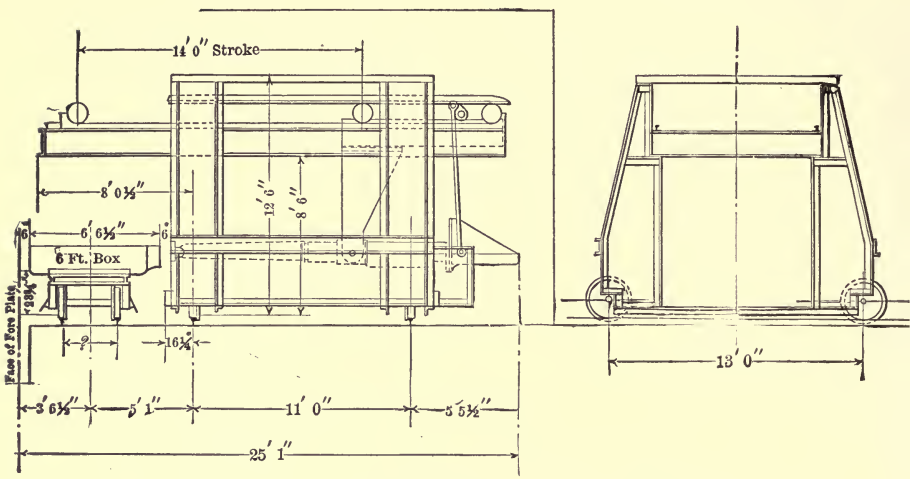

FIG. 81.—Clearance Sketch of Charging Machine.

SEPARATING-HOUSE AND NICKEL REFINERY.

(128 ft by 50 ft., two stories.) See Figs. 74, 76, 77, 83, 84, 85, and 86

Foundations	$3,700
Brick	4,400
Woodwork	2,400
Furnishings	2,100
Fittings	1,500
Sixty-eight nickel-depositing tanks and conductors	2,720
Steel columns and trusses	9.320
Johns asbestos roofing	680
Two separators	2,000
Two sulphite converters	800
Two concentrators	400
Two purifiers	500
Two sludge receivers, generators, etc	1,000
Six supply tanks	420
Two large and eight small receiving tanks	800
One air-compressor and receiver	1,100
One electric motor	700
	$34,540

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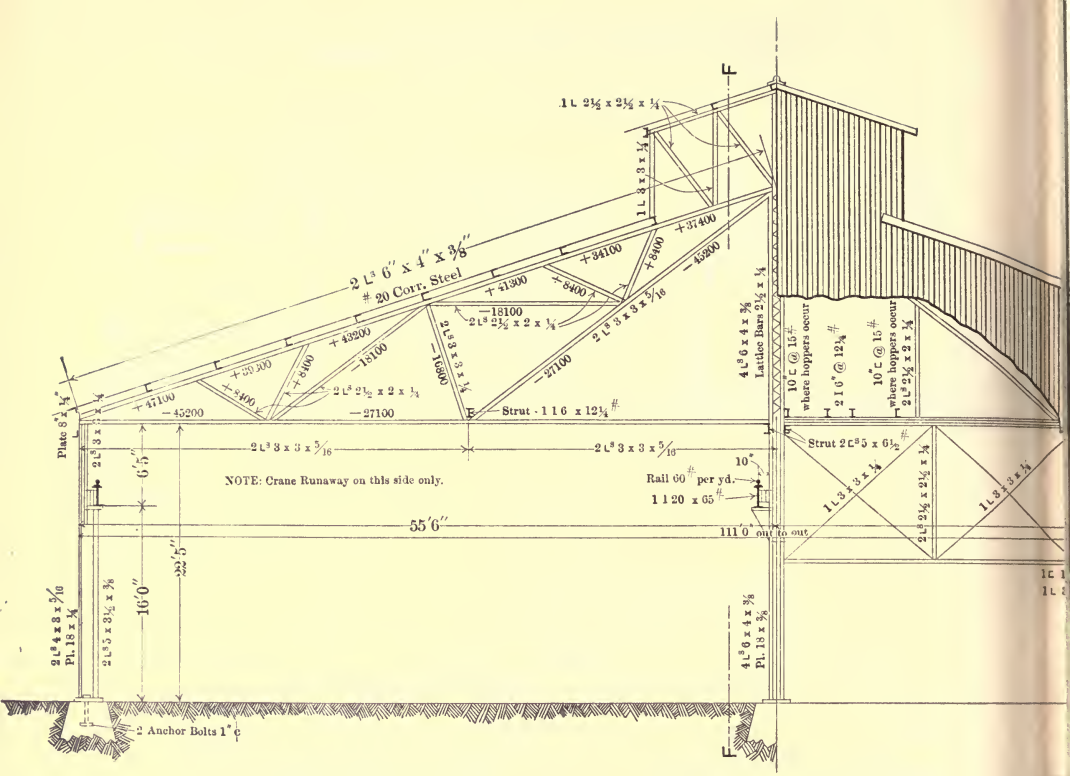


CROSS SECTION C-C FURNACE BUILDING

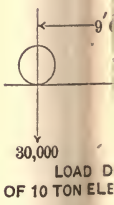
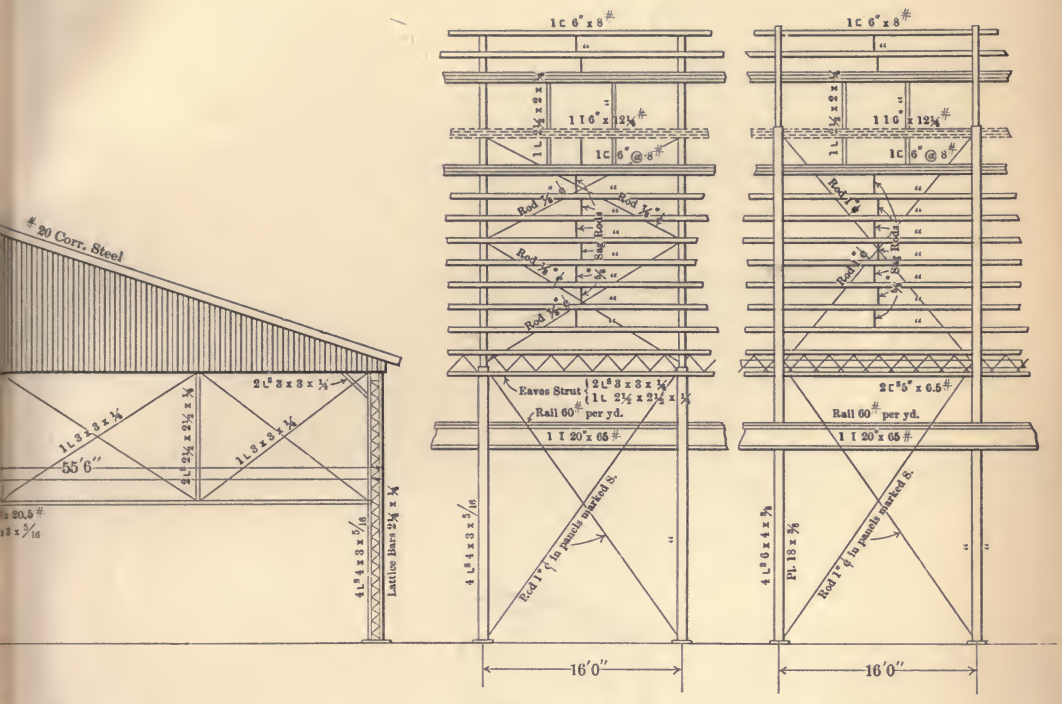
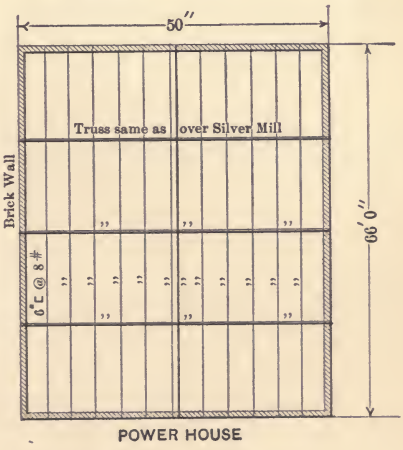


FIG. 82.—Drawing showing Stee. Construction o





the Furnace Building and Power-house.

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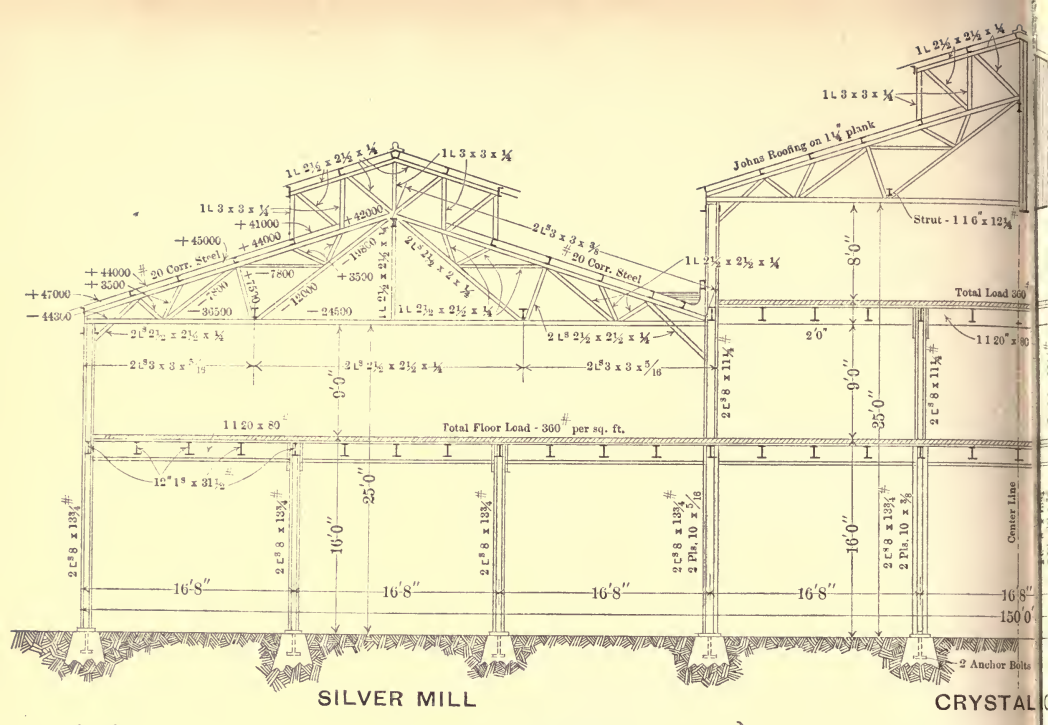
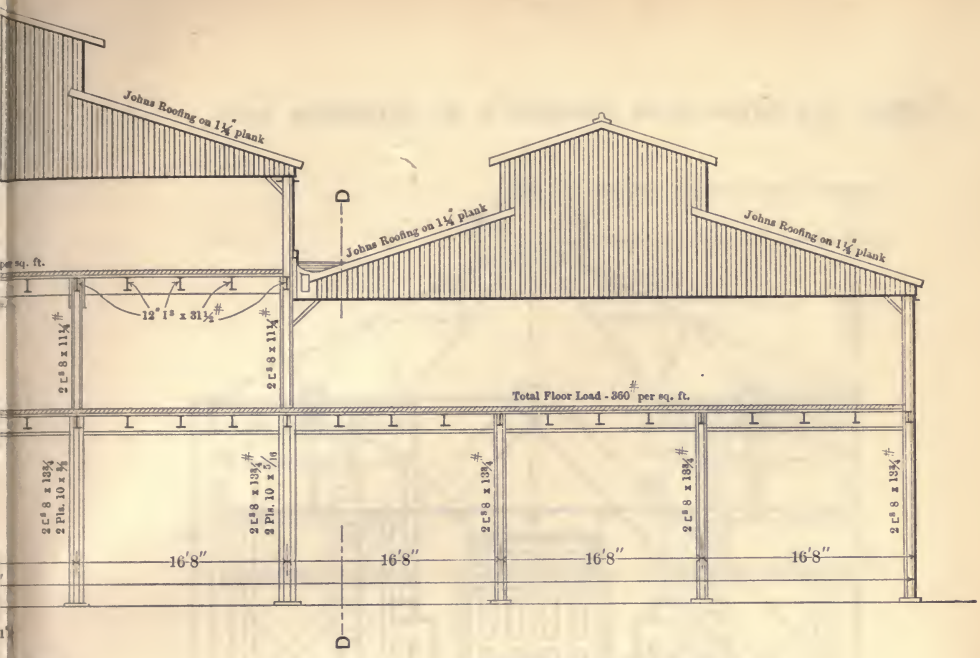


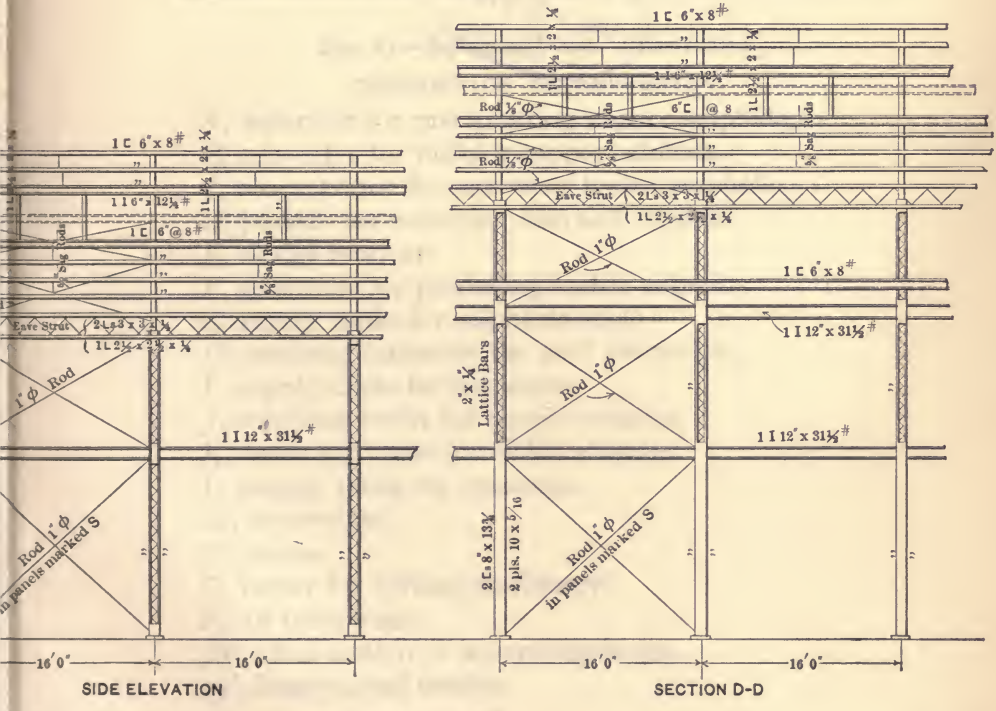
FIG. 86.—Sketch showing Steel Construction of the Silv



LIZING

SEPARATING HOUSE

END ELEVATION


1 C 6"x 8#
1 I 6" x 12½#
1 C 6" @ 8#
Rod 1" ϕ
Eave Strut
1 L 2½ x 2½ x ¼
1" ϕ Rod
1 I 12" x 31½#
Rod 1" ϕ in panels marked S
16'0"
16'0"
SIDE ELEVATION
1 C 6"x 8#
1 I 6" x 12½#
6" C @ 8
Rod 1" ϕ
Eave Strut
2 L 3 x 3 x ¼
1 L 2½ x 2½ x ¼
Rod 1" ϕ
1 C 6"x 8#
1 I 12" x 31½#
2" x ⅜ Lattice Bars
Rod 1" ϕ
1 I 12" x 31½#
2 C 8" x 13¾
2 pls. 10 x 5/16
Rod 1" ϕ in panels marked S
16'0"
16'0"
SECTION D-D

er Mill and the Crystallizing and Separating-house.

[*To face page* 155.]

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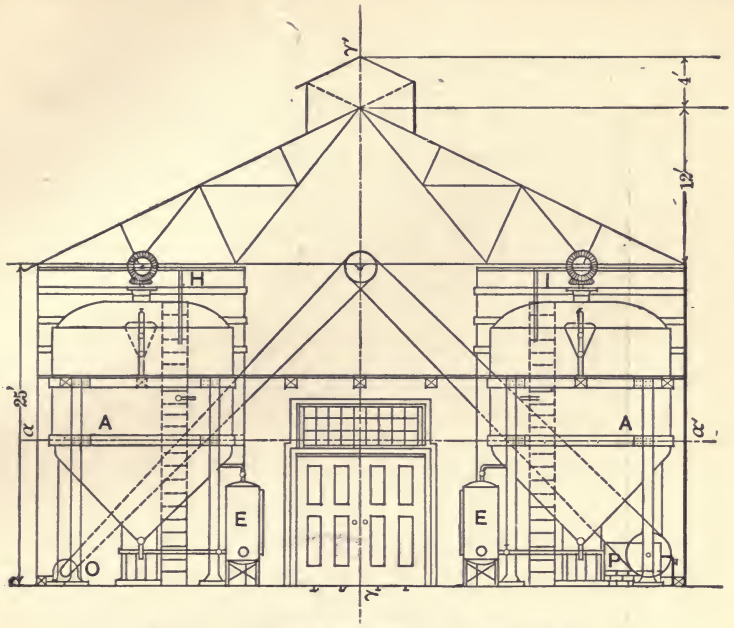

FIG. 83.—Separating-house. Cross-section.

DESCRIPTION OF APPARATUS.

A, separator for precipitating copper sulphide.
B, converter for making copper sulphate.
C, concentrator for removing hydric sulphide.
D, purifier for removing iron and arsenic.
E, sludge receiver.
F, generator for producing hydric sulphide.
G, supply tanks for sulphuric acid.
H, receiving tanks for the acid electrolyte.
I, supply tanks for hot water.
J, receiving tanks for copper solution.
K, receiving tanks for nickel solution.
L, supply tanks for ammonia.
M, air receiver.
N, tracks.
O, motor for driving machinery.
P, air compressor.
$\beta\beta'$, cross-section of separating-house.
$\gamma\gamma'$, longitudinal section.

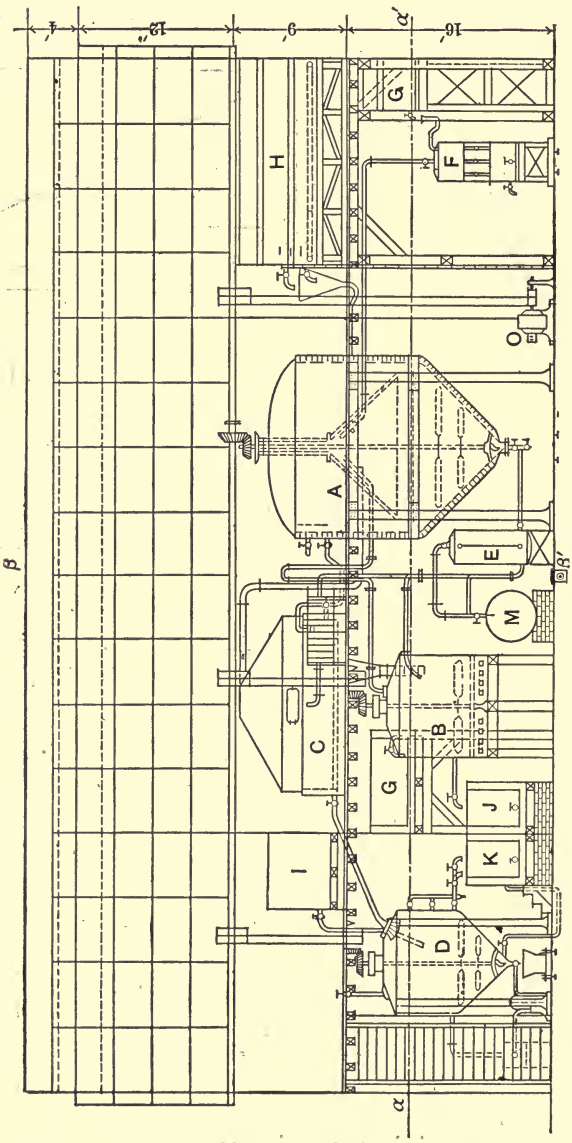

FIG. 84.—Separating-house. Lengths-section.

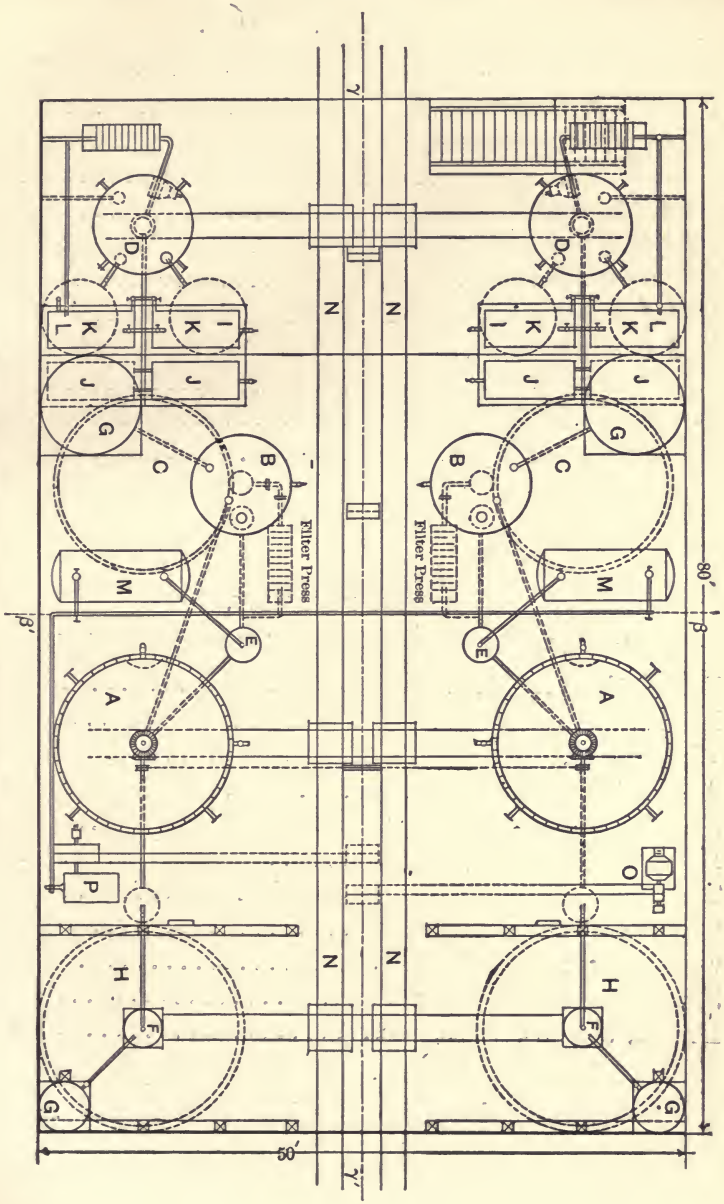

FIG. 85.—Separating-house. Horizontal-section.

CRYSTALLIZING-HOUSE.

(128 ft. by 50 ft., three stories.) See Figs. 74, 76, 77, and 86.

Foundations	$3,700
Brick	2,100
Woodwork	2,400
Furnishings and fittings	1,500
Steel columns and trusses	7,320
Johns asbestos roofing	680
Two oxidizing tanks	200
Two settling tanks	100
Four boiling tanks	600
Twenty crystallizing tanks	1,600
One screen and dryer	100
	$20,300

SILVER REFINERY.

(128 ft. by 50 ft., one story.) See Figs. 74, 76, 77, and 86.

Foundations	$3,700
Brick	2,100
Woodwork	2,400
Furnishings and fittings	1,500
Steel columns and trusses, corrugated iron roof	8,000
Electrolytic parting plant	4,000
Three parting kettles and accessories	1,200
One slime-refining furnace	1,200
One silver cupelling furnace	800
Six boiling and settling tanks	480
Dryers, screens, tools, etc	2,000
	$27,380

OPERATING COSTS AND ANTICIPATED PROFITS.

(Based on a daily output of 75 tons of fine copper, 7.5 tons of fine nickel, and 1500 oz. of silver = 85.227 tons of anodes treated daily.)

Assets.

Plant		$507,028
Stock of anodes in treatment, 2557 tons @ $239.87 per ton	$613,348	
One month's stock on hand of anodes, 2557 tons @ $239.87 per ton	613,348	
Copper in conductors, 40 tons @ $250 per ton	10,000	
Copper in solution, 200 tons @ $230 per ton	46,000	
Nickel in solution, 20 tons @ $680 per ton	13,600	
Permanent stock on hand		1,296,296
Incidentals, contingencies, and sinking fund		196,676
Permanent capital invested		$2,000,000

Liabilities.

Cost of refining copper per ton:		
Labor	$0.75	
Current	1.50	
Supplies, acid, coal, etc.	.67	
Lighting	.08	
	$3.00	
Refining charge	6.00	
Profit per ton of copper	$3.00	

Cost of separating and refining nickel per ton:		
Labor	$0.75	
Current	6.00	
Supplies, acid, coal, etc.	7.17	
Lighting	.08	
	$14.00	
Royalty, with separating and refining charge	200.00	
Profit per ton of nickel		$186
Yearly Operating Cost:		
Copper: 27,000 tons @ $3	$81,000	
Nickel: 2,700 tons @ $14	35,280	$116,280
Price of metal stock purchased annually, 30,684 tons @ $239.87 per ton		7,360,171
Freight charges to market, 29,720 tons @ $5 per ton		148,600
Total expenses		$7,625,051
Value of Total Yearly Output:		
Copper: 27,000 tons @ $240	$6,480,000	
Nickel: 2,700 tons @ $480	1,296,000	
Silver: 540,000 oz. @ 50c	270,000	
		$8,046,000
Total expenses		7,625,051
Total annual profit		$420,949
Percentage of profit on capitalization		21.05%

APPENDIX.

CHRONOLOGICAL LIST OF PATENTS, BOOKS, AND SPECIAL ARTICLES ON ELECTROLYTIC COPPER-REFINING METHODS AND APPARATUS.

1865. *Copper Refining*, English Pat. No. 2,838 of Nov. 3; James Elkington.

1869. *Copper Refining*, English Pat. No. 3,120 of Oct. 27; James Elkington.

1870. *Copper Refining*, U. S. Pat. No. 100,131 of Feb. 22; James Elkington.

1883. "*Electrolysis in the Metallurgy of Copper, Lead, Zinc and other Metals*," by C. O. Mailloux. Mineral Resources of the U. S., Washington, pp. 627–658.

1884. "*Data on the Oker Refinery*," by H. Froelich. Elektrotechn. Zeitschrift, p. 466 et seq. Berlin.

1885. "*Behavior of Constituents of Blister Copper in Electrolytic Refining*," by M. Kiliani. Berg- u. Huetten-Zeitg., p. 249. Berlin.

Method of Arranging Plates in Copper Refining, U. S. Pat. No. 322,170 of July 14; Moses G. Farmer, New York.

1886. "*Electro-Deposition of Gold, Silver, Copper and other Metals*," by A. Watt, London.

Refining Process, German Pat. No. 42,243 of Sept. 14; Siemens & Halske.

Method of Using Endless Cathodes in Copper Refining, U. S. Pat. No. 355,905, Feb. 9; Moses G. Farmer, New York.

"*Einfluss der Stromdichte auf die Festigkeit des Kathodenniederschlags*," by H. Hübl Mitth. des K. u. K. militärgeogr. Instituts, 6, p. 51.

1888. *Copper Refining*, German Pat. No. 53,782 of March 1; Carl Hoepfner.

Copper Refining, U. S. Pat. No. 393,526 of Nov. 27; H. Smith.

"*Grundriss der Elektrometallurgie*," by C. A. Balling, Stuttgart, Germany.

1889. *Refining Process*, German Pat. No. 48,959 of Jan. 3; Siemens & Halske.

1890. "*The Electrolytic Separation of Metals*," by G. Gore, London.

1891. "*The Electro-Deposition of Metals*," by G. Gore, London.

"*The Art of Electro-Metallurgy*," by G. Gore, London.

Copper Refining Apparatus, U. S. Pat. No. 465,525 of Dec. 22; H. Hayden.

1892. "*L'Electrolyse*," by H. Fontaine. Baudry et Cie, Paris.

"*Thofehrn's Electrolytic Refining Process*," by H. Fontaine. The Mineral Industry, Vol. I, p. 163.

"*A Treatise on Electro-Metallurgy*," by W. G. McMillan, London.

Arrangement of Electrodes, U. S. Pats. Nos. 467,350 and 467,484 of Jan. 19; Otto Stalmann.

"*Practical Notes on the Electrolytic Refining of Copper*," by Lieut. F. B. Badt. Proc. Am. Inst. Elect. Eng'rs, June 8. Chicago, Ill.

1893. "*Thofehrn Process of Purifying Solutions*," Berg- u. Huetten-Zeitg., Bd. LII, p. 53, nach Revue Industrielle fuer 1892, No. 24 et seq., by Carl Hering.

"*American Practice in Electrolytic Copper Refining*," by Titus Ulke. The Mineral Industry, Vol. II, pp. 273–286.

"*Thofehrn's Improved Electrolytic Process*," by Hippolyte Fontaine. The Mineral Industry, Vol. II, p. 282. New York.

1894. "*Handbuch der Metallhuettenkunde*," Bd. I and II, by Carl Schnabel. Springer, Berlin.

"*Zur Elektrolytischen Gewinnung von Kupfer nach dem Hoepfnerschen Verfahren*," by E. Jensch. Chem. Zeitg., p. 1906. Berlin.

"*Progress in Electrolytic Refining of Copper during* 1893," by T. Ulke. The Mineral Industry, Vol. III. New York.

Arrangement of Electrodes, U. S. Pat. No. 514,275 of Feb. 6; T. Randolph.

1895. "*Data on the Marchésé Process at Stolberg*," by E. Cohen. Zts. Elektrochemie, Jahrg. II, S. 25.

"*Progress in Electrolytic Refining of Copper during* 1894," by T. Ulke. The Mineral Industry, Vol. IV, New York.

1895. *Car and Set of Molds for Casting Anodes Direct from Converters*, U. S. Pat. No. 539,270, May 14; H. Hixon and J. A. Dyblie.

"*The Electrolytic Refining of Copper*," by M. Barnett. Peters' Modern Copper Smelting, pp. 576–606. New York.

1896. "*Elektro-Metallurgie*," by W. Borchers. Braunschweig, pp. 166–217.

"*The Progress of Electrochemistry and Electrometallurgy in* 1895," by W. Borchers. The Mineral Industry, Vol. IV, pp. 806–808.

"*Improvements in the Electrolytic Refining of Copper*," by T. Ulke. Engineering and Mining Journal, Nov. 14. New York.

Apparatus for Electrolytic Circulation, U. S. Pat. No. 563,093 of June 30; A. E. Schneider and Oscar Szontagh.

"*Present Method of Treating Slimes from the Copper Refineries*," by T. Ulke. The Engineering and Mining Journal, Nov. 28.

"*The Anaconda Refinery*." The Engineering and Mining Journal, Sept. 19, pp. 271–273. New York.

"*Progress in the Electrolytic Refining of Copper*," by T. Ulke. The Mineral Industry, Vol. V, p. 89. New York.

1897. "*Electric Smelting and Refining*," by W. Borchers and Walter G. McMillan. London.

"*Copper Refining*," by J. B. C. Kershaw. The Electrician, London, Jan. 8, pp., 337, 338.

"*Tank Residues in Electrolytic Copper Refineries*," by Edward Keller. Journal Am. Chem. Soc., XIX, No. 10.

"*Copper Refining*," by John B. C. Kershaw. The Electrician, Jan. 18, pp. 385, 386. London.

"*Electric Copper Refining in the United States*," by T. Ulke. Cassier's Magazine, Sept. New York.

1898. "*Progress in Electrolytic Copper Refining in* 1897," by T. Ulke. The Mineral Industry. Vol. VI, pp. 238–244. New York.

"*Handbook of Metallurgy*," by Carl Schnabel. Translated by Henry Louis, London. Vol. I, pp. 260–274.

"*Die Verarbeitung des Elektrolyten in Amerikanischen Kupferwerken*," by T. Ulke. Zts. f. Elektrochemie, 4, 309.

1899. *Method of Producing Electrolytic Copper Wirebars*, U. S. Pat. No. 638,917 of Dec. 12; Elisha Emerson, Providence, R. I.

Method of Electrolytically Refining Copper, U. S. Pat. No. 617,886; Elisha A. Smith, Anaconda, Mont.

1899. "*The Electrolysis and Refining of Copper*," by Edward Keller. The Mineral Industry, Vol. VII, pp. 229–260. New York.

"*Einfluss der Temperatur des Elektrolyten in der Kupferraffination*," by Foerster and Seidel. Zts. f. Elektrochemie, 5, 508.

Mold for Casting Anodes, U. S. Pat. No. 631,471 of Aug. 22; J. T. Morrow, Great Falls, Mont.

1900. "*Treatment of Silver Slimes in Electrolytic Copper Refining*," by J. C. Roberts. Colorado School of Mines Quarterly for May. Golden, Col.

"*Progress in the Electrolytic Refining of Copper during* 1899," by T. Ulke. The Mineral Industry, Vol. VIII, pp. 184–188, New York.

1901. "*The Present Status of the Electrolytic Refining Industry in the United States*," by T. Ulke. Electrical Review, Jan. 12, p. 85. New York.

Plant for the Electrodeposition of Metals, U. S. Pat. No. 687,800 of Dec. 3; Arthur L. Walker, Perth Amboy, N. J.

"*The Raritan Copper Works*," by Lawrence Addicks. The Mineral Industry, Vol. IX, pp. 261–276. New York.

"*Progress in the Electrolytic Refining of Argentiferous Copper*," by T. Ulke. The Mineral Industry, Vol. IX, pp. 223–234. New York.

Rapidly Rotating Mandrels, British Pat. No. 9,731; S. O. Cowper-Coles.

Improved Form of Cathode Plate, U. S. Pat. No. 683,263 of Oct. 12; E. G. Elliott and V. Kishner, Perth Amboy, N. J.

Improved Form of Cathode Plate, U. S. Pat. No. 684,291; W. A. McCoy, Perth Amboy, N. J.

1902. *Metallurgical Crane*, U. S. Pat. No. 697,788 of April 15; David W. Blair.

"*Electrolytic Process of Recovering Copper*," by N. S. Keith. Electrical Review, Vol. 40, No. 12, of March 22. New York.

Art of Refining Composite Metals, U. S. Pat. No. 694,699 of March 4; T. Ulke, Sault Ste. Marie, Ont.

"*Progress in the Electrolytic Refining of Copper in* 1901," by T. Ulke. The Mineral Industry, Vol. X, pp. 217–228. New York.

'*Treatment of Slimes from the Electrolytic Refining of Copper*," by Robert L. Whitehead. The Mineral Industry, Vol. X, pp. 229–230. New York.

"*Corrosion in Depositing Copper*," by H. Sayer and F. S. Spiers. Electrochemist and Metallurgist, April, p. 103. London.

1902. "*Progress in the Making of Blue Vitriol*," by O. Hofmann. The Mineral Industry, Vol. X, pp. 231–242. New York.

"*Electrochemical Polarization*," by C. J. Reed. Journal of the Franklin Institute, April. Philadelphia, Pa.

"*Elektro-Metallurgie*," 3. Auflage, by W. Borchers, pp. 182–268 incl. Braunschweig, Germany.

"*Electro-Plating and Electro-Refining of Metals*," by Arnold Philip. Being a revision of Watt's "Electro-Deposition." London.

"*The Electrolytic Dissolution of Soluble Metallic Anodes*," by Woolsey McA. Johnson. Trans. Am. Electrochem. Soc., Vol. II, pp. 171–173. Philadelphia.

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